The Principles of

Thoracic Anaesthesia

Past and Present

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TO

PROFESSOR R M F PICKEN

Provost of the Welsh National School of Medicine

to whose far sighted encouragement the development of the Department of Anaesthetics at Cardiff owes so much

AND TO

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Nuffield Professor of Anaesthetics in the University of Oxford

whose generous giving of both wisdom and opportunity one of us has had the good fortune to receive and the desire to emulate

PREFACE

THAT an anaesthetist needs to be a doctor and one well trained in the principles of anatomy, physiology and pharmacology, as well as of other sciences as applied to his art, is a belief by no means universally accepted. These qualities we believe are needed particularly when employing the techniques of anaesthesia used in thoracic surgery, for in these circumstances the most fundamental mechanisms of life are upset. Yet to onlookers, and they have included not a few thoracic surgeons of international repute, anaesthesia for thoracic surgery nowadays looks absurdly easy, consisting apparently of little more than a rhythmic and monotonous squeezing of a bag. In fact, in more than one clinic abroad, a mechanical device takes the place of the human hand, the whole affair being looked after by a machine minder directed by the surgeon.

By such apparently simple means, intrathoracic operations of the greatest complexity are carried out as a daily routine, and the risk of a fatal outcome during such an operation is probably little more than that during an abdominal operation of similar complexity. That this is so, is largely, if not entirely, due to safe anaesthesia. It must be a source of wonder that for over fifty years the practical expression of principles on which the present-day techniques are based eluded men of the calibre of Matas and Sauerbruch. As recently as 1937 in a book on thoracic surgery, at the time regarded as authoritative, the method of anaesthesia described had not changed since it was put forward in 1908 by Tiegel.

Let no one readily assume that because squeezing a bag is a simple manoeuvre, anaesthesia for thoracic operations is also simple, for behind that simple squeezing lies an accumulation of knowledge and experience of the physiology and physics of respiration, the exchange of gases between blood and alveoli and the pharmacology of a number of drugs unused in clinical medicine till a few years ago.

The early development of anaesthesia for thoracic surgery was characterized by the fact that interest in it was limited to surgeons, and an important literature on this subject has accumulated. Unfortunately, this literature seems to be little known, for scarcely a month goes by, but an instrument, technique, or idea, which had already been described or investigated by earlier workers, is rediscovered. We feel that the proper understanding of present day methods of anaesthesia for thoracic operations, if not dependent on, is at any rate enhanced by, a knowledge of the difficulties encountered by the pioneers of thoracic surgery, and how they were overcome. To those

Another acknowledgment we would like to make is for the constant co-operation and interest in our work shown by our colleagues at the South Wales Thoracic Centre at Sully Hospital, in particular Mr Dillwyn Thomas It is a pleasure and a constant stimulus to us to belong to the very lively team of workers at that hospital

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conducting research into new forms of anaesthesia or developing new instruments for this purpose, such knowledge is essential

This is not a 'how to do-it' book, since such a book to be complete would necessarily have to include a detailed account of the anatomy and physiology of respiratory function, as well as of the physics and mechanics of breathing and of gas exchange, and of the pharmacology of the various drugs used We have, in fact, deliberately omitted the practical details of present-day techniques since they are as likely to change as those of thirty years ago

Being active clinical anaesthetists ourselves, we are aware of the practical importance of proper equipment and how a seemingly trivial modification of an apparently useless instrument can make possible a technique until then elusive Some emphasis in this book, therefore, is placed on the instruments used in these anaesthetic techniques Not only because they have been and are of great practical interest, but because in addition they form convenient pegs on which to hang the story of how the problems posed by the open chest have been overcome

We offer no apology for writing in a consciously simple manner The extra time involved has not been small, but by it we hope we have made clearer to practising anaesthetists and research workers parts of a complicated story formerly little known Many of the illustrations are poor, and fall far short of present day standards They are the originals, however, and we have no means other than their authors' own descriptions to understand their details

Grateful thanks are given to the authors and publishers of the many books and journals listed, for their permission to reproduce illustrations, and for the help given both by the library staff of the Royal Society of Medicine and by Miss Lumley Jones, the librarian of the Welsh National School of Medicine We also received invaluable assistance from Drs Marcel and Stephen Gang and R Armstrong with translations Our thanks are also due to Dr E A Underwood of the Wellcome Historical Medical Museum for several of the illustrations, to Mr A Welch of Cardiff and to Mr Wilson and the staff of the Photographic Department of the Royal Society of Medicine for their expert photographs and to Miss June Williams for several of the line drawings Acknowledgment is made to Messrs A Charles King Ltd , The Genito-Urinary Manufacturing Co Ltd and Down Brothers Mayer and Phelps Ltd for the kind loan of certain blocks We are specially grateful to Dr L West our colleague at Sully Hospital for his careful reading of the manuscript and for his many helpful criticisms and suggestions Needless to say, our Secretary, Miss M Fairweather, and her assistants, Misses R Riehl and A Curnuck, have our earnest gratitude for their unfailing energy, care and cheerfulness in preparing the manuscript

CONTENTS

		PAGE
PREFACE		v
ILLUSTRATIONS		xi
INTRODUCTION		1

PART I

THE PNEUMOTHORAX PROBLEM AND ITS SOLUTION

CHAPTER		
I	THE PROBLEM	4
II	SOLUTIONS OF THE PROBLEM	10
III	CONTROLLED RESPIRATION	14
IV	CLOSURE OF THE CHEST WALL	23

PART II

HISTORICAL BACKGROUND

V	RESUSCITATION	28
VI	THE BEGINNINGS OF INTUBATION	39
VII	EARLY CHEST ANAESTHESIA	44
VIII	THE POSITIVE PRESSURE PERIOD	48
IX	INSUFFLATION	67
X	EARLY AUTOMATIC DEVICES FOR RHYTHMIC INFLATION	78

PART III

METHODS IN USE TO-DAY

XI	MODERN AUTOMATIC DEVICES FOR RHYTHMIC INFLATION	86
XII	THE DEVELOPMENT OF TRACHEAL AND BRONCHIAL INTUBATION AND OF THE CONTROL OF SECRETIONS	103
XIII	ANAESTHETIC AGENTS CONCLUSION	143

Appendix I	INSTRUCTIONS FOR RESUSCITATION (Paris, 1822)	151
Appendix II	BIOGRAPHICAL NOTES	152
INDEX		163

ILLUSTRATIONS

		PAGE
Fig 1	Diagram of Pressures acting upon the lung	5
Fig 2	Diagram showing the effect of Thoracotomy	5
Fig 3	Diagram of intrabronchial pressure during Thoracotomy	6
Fig 4	Spirometer tracing showing effect of positive pressure	10
Fig 5	Water valve	11
Fig 6	Pressure curve normal breathing	16
Fig 7	Pressure curve, spontaneous positive pressure breathing	16
Fig 8	Pressure curve controlled respiration (Fig 6 7, 8 after Mautz F R in *Medical Physics* by Otto Glasser Chicago Ill 1944 p 1514)	16
Fig 9	Diagram of Water Seal Closure after Thoracic operation	24
Fig 10	Vesalius experiments with Artificial Respiration *De Corporis Humanis Fabrica*, Basle 1555 Vol 7 p 708	28
Fig 11	Royal Humane Society s Apparatus (1806) (from the Society s Annual Report for 1806)	32
Fig 12	Nooth s Pump (1788) (Goodwin Edmund *The Connexion of Life with Respiration* London 1788 facing p 115)	33
Fig 13	Curry s Resuscitation Apparatus (1792) (Curry, James *Popular Observations on Apparent Death from Drowning* Northampton 1792 facing p 94)	34
Fig 14	Curry s Cannula in Use (Curry, James *Observations on apparent Death* 2nd ed London 1815 facing p 205)	35
Fig 15	Leroy s Safety Bellows and Instruments for Intubation (*J de Physiol* 1827, 7 45)	36
Fig 16	Erichsen s Resuscitation Pump (1845) (*Edinb med & surg J* 1845 63 1)	37
Fig 17	Diagram of Erichsen s Pump (1845) (*Ibid*)	37
Fig 18	Chaussier s Bag and Mask for Inflation (1780) (*Hist Soc Roy de Med* 1780-81 346 plate 13)	39
Fig 19	Chaussier s Oxygen Therapy Outfit (1780) (*Ibid*)	40
Fig 20	Chaussier s Cannula (1807) (Matas R *J Amer med Ass* 1900 34 1371)	41
Fig 21	Depaul s Cannula (1845) (*Dict Encyclopedique Sci med* Paris 13th series 13 p 601)	41
Fig 22	Ribemont s Tube (1878) (*Progr med* Paris 1878 6 355)	42
Fig 23	O Dwyer s Tube and Instruments for Laryngeal Intubation in Diphtheritic Croup (1885) (*N Y med J* 1885 41–42 145)	42
Fig 24	The Original Fell Apparatus for Artificial Respiration (1893) (Matas R *J Amer med Ass* 1900 34 1470)	44
Fig 25	The Fell O Dwyer Apparatus (*c* 1888) (Matas R *ibid*)	45
Fig 26	Matas Modification of the Fell O Dwyer Apparatus (1900) (Matas, R *ibid*)	45
Fig 27	Tuffier and Hallion s Method (1896) (*Pr med* 1906 14 57)	46
Fig 28	Sauerbruch s Experimental Negative Pressure Box used in Open Chest Operations on Dogs (*Mitt Grenzgeb Med Chir* 1904 13 399)	49

ILLUSTRATIONS

		PAGE
Fig 1	Diagram of Pressures acting upon the lung	5
Fig 2	Diagram showing the effect of Thoracotomy	5
Fig 3	Diagram of intrabronchial pressure during Thoracotomy	6
Fig 4	Spirometer tracing showing effect of positive pressure	10
Fig 5	Water valve	11
Fig 6	Pressure curve normal breathing	16
Fig 7	Pressure curve spontaneous positive pressure breathing	16
Fig 8	Pressure curve controlled respiration (Fig 6 7 8 after Mautz, F R in *Medical Physics* by Otto Glasser, Chicago Ill 1944, p 1514)	16
Fig 9	Diagram of Water Seal Closure after Thoracic operation	24
Fig 10	Vesalius experiments with Artificial Respiration *De Corporis Humanis Fabrica* Basle 1555 Vol 7 p 708	28
Fig 11	Royal Humane Society s Apparatus (1806) (from the Society s Annual Report for 1806)	32
Fig 12	Nooth s Pump (1788) (Goodwin Edmund *The Connexion of Life with Respiration* London 1788 facing p 115)	33
Fig 13	Curry s Resuscitation Apparatus (1792) (Curry James *Popular Observations on Apparent Death from Drowning* Northampton 1792 facing p 94)	34
Fig 14	Curry s Cannula in Use (Curry James *Observations on apparent Death* 2nd ed London 1815 facing p 205)	35
Fig 15	Leroy s Safety Bellows and Instruments for Intubation (*J de Physiol* 1827 7 45)	36
Fig 16	Erichsen s Resuscitation Pump (1845) (*Edinb med & surg J* 1845 63 1)	37
Fig 17	Diagram of Erichsen s Pump (1845) (*Ibid*)	37
Fig 18	Chaussier s Bag and Mask for Inflation (1780) (*Hist Soc Roy de Med* 1780–81 346 plate 13)	39
Fig 19	Chaussier s Oxygen Therapy Outfit (1780) (*Ibid*)	40
Fig 20	Chaussier s Cannula (1807) (Matas R *J Amer med Ass* 1900 34 1371)	41
Fig 21	Depaul s Cannula (1845) (*Dict Encyclopedique Sci med* Paris 13th series 13 p 601)	41
Fig 22	Ribemont s Tube (1878) (*Progr med* Paris 1878 6 355)	42
Fig 23	O Dwyer s Tube and Instruments for Laryngeal Intubation in Diphtheritic Croup (1885) (*N Y med J* 1885 41–42 145)	42
Fig 24	The Original Fell Apparatus for Artificial Respiration (1893) (Matas R *J Amer med Ass* 1900 34 1470)	44
Fig 25	The Fell O Dwyer Apparatus (*c* 1888) (Matas R *ibid*)	45
Fig 26	Matas Modification of the Fell O Dwyer Apparatus (1900) (Matas, R *ibid*)	45
Fig 27	Tuffier and Hallion s Method (1896) (*Pr med* 1906 14 57)	46
Fig 28	Sauerbruch s Experimental Negative Pressure Box used in Open Chest Operations on Dogs (*Mitt Grenzgeb Med Chir* 1904 13 399)	49

PAGE

Fig 29 Negative Pressure Operating Chamber for Use in Experimental Open Chest Operations on Dogs (Sauerbruch 1904) (*Ibid*) 49
Fig 30 Negative Pressure Operating Chamber (Sauerbruch, 1904) (*Ibid*) 50
Fig 31 Woillez Spirophore (1876) (Depaul *Dict Encyclopedique Sci Med*, Paris 13th Series 13 609) 50
Fig 32 The Original Brauer Apparatus for Positive Pressure Anaesthesia in Open Chest Surgery (1904) (*Mitt grenzgeb Med Chir* 1904, 13, 483) 51
Fig 33 Brauer s Second Apparatus (1905) (Brauer, L *Dtsch med Wschr* 1905 31, 1489) 52
Fig 34 Murphy s Positive Pressure Apparatus (1905) (*Boston med & surg J* 1905 152 428) 53
Fig 35 Diagram of Murphy s Apparatus (1905) 53
Fig 36 Meyer's Combined Positive and Negative Pressure Apparatus (1909) (*J Amer med Ass* 1909 53 1984) 54
Fig 37 The Positive Pressure Chamber of Meyer s Combined Positive and Negative Pressure Apparatus (1909) (*Ibid*) 54
Fig 38 View of the Interior of Meyer s Negative Pressure Operating Chamber (1909) (*Ibid*) 54
Fig 39 Robinson s Improved Positive Pressure Apparatus (1910) (*Surg Gynec Obstet* 1910 10 287) 55
Fig 40 The Anaesthetist Seated in Robinson s Positive Pressure Cabinet (*Ibid*) 55
Fig 41 Front of Robinson s Cabinet from the Interior (*Ibid*) 55
Fig 42 Kuhn s Positive Pressure Apparatus (1905) (*Dtsch Z Chir* 1905 78 503) 56
Fig 43 Kuhn s Revised Positive Pressure Apparatus (1906) (*Dtsch Z Chir* 1906 81 69) 57
Fig 44 Diagram of Kuhn s Revised Positive Pressure Apparatus (1906) (*Ibid*) 57
Fig 45 Kuhn s Positive Pressure Closed Circuit Apparatus (1906) (*Ibid*) 58
Fig 46 Diagram of Kuhn s Positive Pressure Closed Circuit Apparatus (1906) 58
Fig 47 Brat and Schmieden s Apparatus (1908) (*Munch med Wschr* 1908 55 2421) 59
Fig 48 Tiegel s First Apparatus (1908) (*Zbl Chir* 1908 22 679) 60
Fig 49 Tiegel s vomit catcher (1909) (*Beitr klin Chir* 1909 64 358) 60
Fig 50 Tiegel s second apparatus (1909) (*Ibid*) 60
Fig 51 The Tiegel Henle Positive Pressure Apparatus Used in Sauerbruch s Clinic in 1937 (Sauerbruch F and O Shaugnessy L *Thoracic Surgery* London 1937 p 26 Fig 17) 61
Fig 52 The Lotsch Positive Pressure Apparatus (1910) (Lotsch F *Arch klin Chir* 1910 93 285) 62
Fig 53 Bunnell s Spring Loaded Expiratory Valve (1912) (*J Amer med Ass* 1912 58 835) 62
Fig 54 General View of Morriston Davies Positive Pressure Anaesthetic Machine (1911) (*Brit med J* 1911 ii 61) 63
Fig 55 Morriston Davies Endotracheal Tube (1911) (*Ibid*) 63
Fig 56 Diagram of Morriston Davies Positive Pressure Apparatus (1911) (*Ibid*) 63
Fig 57 Drager Positive Pressure Apparatus 1948 (Drager Catalogue Liste M3 1) 65

PAGE

Fig 58 Meltzer and Auer Insufflation Apparatus (1913) (Meltzer, S J (1913) *17th Int Congr med*, London Sub section VII (b)) 68
Fig 59 Barthelemy and Dufour s Endotracheal Insufflation Method (1907) (*Pr méd* 1907, 15 475) 69
Fig 60 Volhard s Method of Artificial Respiration (1908) (*Munch med Wschr* 1908 55 209) 70
Fig 61 Elsberg s First Machine for Endotracheal Insufflation Anaesthesia (1910) (*Medical Record* 1910 77, 494) 72
Fig 62 Elsberg s Portable Insufflation Apparatus (1911) (*Ann Surg* 1911, 53, 161) 73
Fig 63 and 64 Janeway s Intermittent Insufflation Apparatus (1912) (*Ann Surg* 1912 56 328) 74
Fig 65 Ehrenfried s Insufflation Apparatus (From Gwathmey J T *Anaesthesia* New York 1914, p 426) 75
Fig 66 Robinson s Insufflation Apparatus (1912) (*Surg Gynec Obstet* 1912 14 462) 75
Fig 67 Shipway s Insufflation Apparatus (1914) (*Lancet* 1914 ii 104) 76
Fig 68 Janeway and Green s Rhythmic Inflation Apparatus (1909) (*J Amer med Ass* 1909 53 1975) 78
Fig 69 Janeway s Apparatus for Assisted or Controlled Respiration (1913) (*Ann Surg* 1913 58 927) 81
Fig 70 The Drager Pulmotor (1911) (Dragerwerk, Lubeck) 81
Fig 71 Diagram of the E and J Resuscitator Apparatus—Inspiratory Phase (*Popular Science* 1947 July p 129) 82
Fig 72 Diagram of the E and J Resuscitator Apparatus—Expiratory Phase (*Ibid*) 82
Fig 73 Lundy s Pulmonary Ventilator (1932) (*Proc Mayo Clin* 1932, 7, 225) 83
Fig 74 The Frenckner Spiropulsator (1934) (*Acta oto laryng* 1934 Suppl 20 112) 87
Fig 75 Diagram of Frenckner Spiropulsator (*Ibid*) 88
Fig 76 The First Crafoord Modification of Frenckner s Spiropulsator (*Acta Chir Scand* 1938 81 Suppl 54 p 52) 89
Fig 77 Diagram of Crafoord's Modification of Frenckner s Spiropulsator (*Ibid*) 89
Fig 78 The First Commercial Model of the Spiropulsator (1940) (Anderson E, Crafoord C and Frenckner P, *Acta oto laryng* 1940 28 100) 90
Fig 79 Diagram of the Spiropulsator Anaesthetic Apparatus (Anderson E Crafoord C and Frenckner P *Ibid*) 90
Fig 80 The Frenckner Spiropulsator Mechanism (1949) (Morch E T *Anaesthesi* Copenhagen 1949 p 331) 91
Fig 81 Aga Stille Anaesthetic Apparatus with Spiropulsator (1950) (Aga Catalogue) 92
Fig 82 Diagram of Aga Stille Anaesthetic Apparatus with Spiropulsator (Morch E T *Anaesthesi* Copenhagen 1949 p 330) 92
Fig 83 Mautz s Automatic Respiration Apparatus (1939) (*Proc Soc Exp Biol N Y* 1939 42 190) 93
Fig 84 Mautz s Automatic Respiration Apparatus connected to Heidbrinck Machine (1941) (*J thorac Surg* 1941 10 544) 93

PG

Fig 85 The Mørch Respirator (*Proc Roy Soc Med* 1947 40 605) 94

Fig 86 James Apparatus for Controlled Respiration (1951) (*Med J Aust* 1950 1 325) 94

Fig 87 Pinson s Automatic Respiration and Suction Apparatus (1944) (*Brit J Anaesth* 1944 19 53) 95

Fig 88 Pinson s Machine ready for use (Courtesy of Dr Pinson and The Photographic Dept Manchester Royal Infirmary) 96

Fig 89 Blease s First Pulmoflator (1946) (Mørch E T *Anaesthesi* Copenhagen 1949 p 336) 97

Fig 90 Blease Pulmoflator (1950) (Blease Equipment Co London) 98

Fig 91 Diagram of Blease Pulmoflator (1950) (Blease Equipment Co, London) 98

Fig 92 Diagram of the Burns Pressure Balance Resuscitator (Courtesy of Mine Safety Appliances Co Pittsburgh) 99

Fig 93 The Bennett Resuscitator (*c* 1946) (After, Motley, H L *J Amer med Ass* 1948 137 370) 100

Fig 94 Mørch s latest Respirator (1952) (*Personal Communication*) 100

Fig 95 Williams Automatic Breathing Attachment (*Brit J Anaesth* 1952, 24 223) 101

Fig 96 Williams Automatic Breathing Attachment on Boyle's Apparatus (*Brit J Anaesth* 1952 24 222) 101

Fig 97 Pugh s Air Pipe (1754) (Pugh B, *A Treatise of Midwifery* London 1754 Plate II) 103

Fig 98 Kite s Intubation Tube (1788) (Kite C *An essay on the Recovery of the Apparently Dead* London 1788 (Courtesy of The Wellcome Historical Medical Library)) 104

Fig 99 Kite s Complete Resuscitation Assembly (1788) (*Ibid*) 104

Fig 100 Curry s Instruments for Resuscitation (1792) (Curry J, *Popular Observations on Apparent Death* Northampton 1792) 105

Fig 101 Curry s Modified Resuscitation Instruments (1815) (Curry J, *Popular Observations on Apparent Death* 2nd edition London 1815 Plate 2) 106

Fig 102 Chaussier s Tube for Intubation of the Larynx in Asphyxia Neonatorum (1806) (Matas R *J Amer med Ass* 1900 34 1373) 106

Fig 103 Royal Humane Society s Resuscitation Instruments (1806) (From the Society Annual Report for 1806) 107

Fig 104 Original Bozzini Endoscope (1806) (Moore I *J Laryng* 1926 41 280) 108

Fig 105 Bozzini s Improved Endoscope (Moore I *op cit* 1926 41 281) 108

Fig 106 Depaul s Tube (1845) (*Dict Encyclopedique Sci Med* 13th series 13 601) 108

Fig 107 Desormeaux Endoscope (1853) (Moore I *J Laryng* 1926 41 283) 109

Fig 108 Trendelenburg s Tracheotomy Tube with Cuff (1871) (*Arch klin Chir* 1871 12 121) 109

Fig 109 Wolffberg s Endobronchial Catheter (1871) (Frenckner P *Acta oto laryng* 1934 Suppl 20 27) 110

Fig 110 Brunton s Aural Endoscope (1865) (Moore I *J Laryng* 1926 41 287) 110

Fig 111 Voltolini s Tracheoscope (1875) (Frenckner P *Acta oto laryng* 1934 Suppl 20 18) 110

Fig 112	Ribemont s Tube (1878) (*Progr med* Paris 1878 6 335)	111
Fig 113	O Dwyer s Tubes and Introducers (1885) (*N Y med J* 1885 41–42, 145)	111
Fig 114	O Dwyer s laryngeal Tube designed for Use with the Fell Resuscitation Apparatus (1900) (Kuhn F, *Dtsch Z Chir* 1905 76 148)	111
Fig 115	Annandale s Tube (1889) (*Brit med J* 1889 1 463)	112
Fig 116	Head s Endobronchial Cannula (1889) (*J Physiol* 1889 10 1 and 279)	112
Fig 117	Werigo s Endobronchial Catheter with Inflatable Cuff (1892) (*Pflüg Arch ges Physiol* 1892 51 321)	112
Fig 118	Eisenmenger s Tube with Cuff and Pilot Balloon (1893) (*Wein med Wschr* 1893 43 199)	113
Fig 119	Maydl s Tube (1893) (*Wein med Wschr* 1893 43 102)	113
Fig 120	Tuffier s Tube with Cuff (1895) (*Pr med* 1906 14 57)	114
Fig 121	Doyen s Tube (1897) (Kuhn F, *Dtsch Z Chir* 1905 76 166)	114
Fig 122	Kirstein s Autoscope (1895) (Frenckner, P *Acta oto laryng* 1934 Suppl 20 18)	114
Fig 123	Kirstein s Autoscope in Use (1895) (Moore I *J Laryng* 1926 41, 362)	114
Fig 124	The Sword Swallowing Method of Oesophagoscopy (1896) (Moore I, *J Laryng* 1926 41 296)	115
Fig 125	Killian s Bronchoscopes (1896) (Courtesy Messrs Down Bros London)	116
Fig 126	van Stockum s Endotracheal Tube and Cuff (1898) (Kuhn F *Dtsch Z Chir* 1905 76 155)	116
Fig 127	Kausch s Stomach Tube with Cuff and Pilot Balloon (1903) (*Berl klin Wschr* 1903 40 753)	117
Fig 128	Macintosh s Oesophageal Tube with Cuff (1951) (*Brit Med J* 1951 ii 545)	117
Fig 129	Loewy and Schrotter s Endobronchial Catheter and Cuff (*Z exp Path Ther* 1905 1 197)	117
Fig 130	Kuhn s Endotracheal Anaesthesia Instruments (1900–11) (Blanluet M P *Pr med* 1911 19 794)	118
Fig 131	Method of Insertion of Kuhn s Tube (*Ibid*)	118
Fig 132	Trendelenburg s Cone for Use with Kuhn s Tube (*Ibid*)	118
Fig 133	Kuhn s Apparatus in Use (*Ibid*)	118
Fig 134	Green s Endotracheal Tube and Cuff with Pilot Balloon (1906) (*Surg Gynec Obstet* 1906 2 519)	119
Fig 135	Hill s Slotted Laryngoscope (1909) (Courtesy Messrs Down Bros London)	119
Fig 136	Hill s Slotted Operating Oesophagoscope (1909) (Courtesy Messrs Down Bros London)	120
Fig 137	Albert s Slotted Bronchoscope (1952) (*Brit J Anaesth* 1952 24 145)	120
Fig 138	Dorrance s Endotracheal Tube and Cuff (1910) (*Surg Gynec Obstet* 1910 11 160)	121
Fig 139	Dorrance s Tube in Place (*Ibid*)	121
Fig 140	Dorrance s Outfit for Chest Anaesthesia (*Ibid*)	121
Fig 141	Morriston Davies Endotracheal Tube with Inflatable Cuff (1911) (*Brit med J* 1911 ii 61)	122
Fig 142	Kuhn s Tube with Inner Catheter for Suction or Insufflation (1912) (*Zbl Chir* 1912 39 73)	122

Fig 143 Laryngoscopy for Anaesthetists Demonstrated by Jackson (1913) (*Surg Gynec Obstet* 1913 17, 507) 122
Fig 144 Chevalier Jackson s Laryngoscope (1913) (*Ibid*) 123
Fig 145 Janeway s Laryngoscope with Curved Blade (1913) (*Ann Surg* 1913 58 927) 123
Fig 146 Janeway s Detachable Inflatable Cuff (1913) (*Ibid*) 123
Fig 147 Rowbotham s Method of Intubation Using a Hill s Laryngoscope (*Brit med J* 1920 11 590) 124
Fig 148 The Rowbotham Two Catheter Method in Use (*Ibid*) 124
Fig 149 Rowbotham s Modified Two Tube Endotracheal Method (1923) (*Brit med J* 1923 1 1090) 125
Fig 150 Magill s Original Pattern Laryngoscope (*c* 1920) (Courtesy Messrs Down Bros London) 125
Fig 151 Magill s and Rowbotham s double Endotracheal Gum Elastic Catheter (1920) (Courtesy Messrs A Charles King Ltd London) 125
Fig 152 Flagg s Apparatus for Endotrachel Inhalation Anaesthesia with Ether (1928) (*Arch Otolaryng* 1928 7, 160) 126
Fig 153 Guedel and Waters New Intratracheal Catheter (1928) (*Anesth and Analg* 1928 7, 238) 126
Fig 154 Guedel and Waters Removable Cuff (1928) (*Arch Oto Rhin Laryng* 1931, 40 1139) 127
Fig 155 Guedel and Waters Tube in Place (1928) (*Ibid*) 127
Fig 156 Gale and Waters Endobronchial Intubation for One Lung Anaesthesia (1931) (*J Thorac Surg* 1931–32 1 432) 128
Fig 157 Flagg s Laryngoscope (1932) (*Arch Otolaryng* 1932 15 844) 128
Fig 158 The Coryllos McKesson Endotracheal Tube (1932) (*Anesth & Analg* 1932 11 138) 129
Fig 159 Frenckner s Tube with Cuff (1934) (*Acta oto laryng* 1934 Suppl 20 p 59) 129
Fig 160 Frenckner s Double Bronchoscope for Bronchospirometry (1934) (*op cit* 1934 Suppl 20 p 74) 130
Fig 161 Zavod Bronchospirometric Catheter (1940) (*J Thorac Surg* 1940 10 27) 130
Fig 162 Frenckner s Bronchoscope for the Insertion of Gas Sampling Endo bronchial Tubes (1934) (*Acta oto laryng* 1934 Suppl 20 p 62) 131
Fig 163 Magill s endotracheal Tube and Cuff with T Connection to Enable Suction to be Carried Out (1935) (*Proc Roy Soc Med* 1935–36 29 649) 131
Fig 164 Magill s Endobronchial Tube and Bronchoscope (1935) (*Proc Roy Soc Med* 1935–36 29 649) 132
Fig 165 Magill s Endobronchial Tubes (later pattern) (Courtesy Medical and Industrial Equipment Company London) 132
Fig 166 Magill s Bronchus Blocker and Inserting Tracheoscope (1935) (*Proc Roy Soc Med* 1935–36 29 650) 133
Fig 167 Magill s Modified Bronchus Blocker and Inserting Instruments (1941) (Nosworthy M D *Proc Roy Soc Med* 1941 34 479) 133
Fig 168 Rovenstine s Endobronchial Tube (1936) (*Surg Gynec Obstet* 1936 63 325) 133

PAGE

Fig 169 Crafoord's Indirect Endotracheal Tube Introducer (1938) (*Acta chir Scand* 1938 81 Suppl 54 p 63) 134
Fig 170 Leroy's Endotracheal Tube Introducer (1827) (*J de Physiol* 1827 7, 45) 134
Fig 171 Crafoord's Bronchial Tamponage (1938) (Nosworthy, M D *Proc Roy Soc Med* 1941, 34 498) 134
Fig 172 The Posture Advocated by Beecher to Prevent Spread of Secretions (1941) (Nosworthy, M D *op cit* 1941 34, 479) 135
Fig 173 Overholt's Position for Thoracotomy (*c* 1945) (Overholt R H, and Langer L *The Technique of Pulmonary Resection*, Springfield, U S A, 1949) 136
Fig 174 Macintosh's Laryngoscope (1943) (Courtesy Longworth Scientific Instruments Co Oxford) (*Lancet*, 1943 i 205) 136
Fig 175 Mushin's Self Inflating Cuff (1943) (*Brit med J* 1943, ii 234) 137
Fig 176 Wilm's Self Inflating Cuff (1904) (Kuhn F *Dtsch Z Chir* 1905 76 485) 137
Fig 177 Halton's Bronchial Occluder (1943) (*Lancet* 1943 i 12) 137
Fig 178 Thompson's Bronchus Blocker (1943) (Courtesy Messrs Genito Urinary Co Ltd London) 138
Fig 179 Clawed Bronchial Suction Blocker (Moody Trent and Newton 1947) (*J Thorac Surg* 1947 16 258) 138
Fig 180 Magill's Bronchial Blocker (1948) (Courtesy Messrs Medical and Industrial Equipment Co Ltd London) 139
Fig 181 Rubber Covered Spiral Wire, Endobronchial Tube (Ruth Grove and Keown 1948) (*Anesthesiol* 1948 9, 422) 139
Fig 182 Bjork and Carlens Double Lumen Catheter (1950) (*J Thorac Surg* 1950 20 151) 140
Fig 183 Hess Endobronchial Catheter with Cuff and Locating Spur (1912) (*Dtsch Arch klin Med* 1912 106) 140
Fig 184 Mully's Upper Lobe Bronchus Blocker (1950) (*Schweiz Z Tuberk* 1950 Suppl *Biblio Tuberk* Fasc 4) 140
Fig 185 Diagram of Upper Lobe Bronchus Blocker in Position (After Mully) 140
Fig 186 Anaesthetic Rotameters (Neu) (1910) (*Munch Med Wschr* 1910 57 1874) 144
Fig 187 The Final Model of Neu's Anaesthetic Apparatus (1911) (*Arch klin Chir* 1911 95 553) 144
Fig 188 Jackson's Carbon Dioxide Absorption Apparatus (1915) (*J Lab and Clin Med* 1915 1 1) 145
Fig 189 Jackson's First Experimental Carbon Dioxide Absorption Apparatus (1915) (*Ibid*) 145
Fig 190 Schwann's Circle Carbon Dioxide Absorption Mine Rescue Apparatus (1853) (Waters R M *Anesthesiol* 1943 4 598) 146
Fig 191 Improved Model of Jackson's Apparatus (1916) (*op cit* 1915 1 645) 146
Fig 192 Jackson's To and Fro Absorber for Economical Ether Anaesthesia in Animals (1916) (*J Lab Clin Med* 1916 2 94) 147
Fig 193 To and Fro Absorption and the Water's Canister (1924) (*Anesth & Analg* 1924 3 20) 147
Fig 194 Ludolph Brauer (*Beitr Klin Tuberk* 1925 86 4) 152

PAGE

Fig 195 François Chaussier (from the Portrait Collection of the Royal Society of Medicine) 152
Fig 196 William Cullen (Peck, T W and Wilkinson K D *William Withering of Birmingham* Bristol 1950) 153
Fig 197 James Curry (from the Portrait Collection of the Royal Society of Medicine) 153
Fig 198 Anne Jean Henri Depaul (Courtesy Wellcome Historical Medical Museum) 153
Fig 199 Charles Albert Elsberg (*Bull Neurol Inst N Y* 1936 5 Frontispiece) 154
Fig 200 William Hawes (from the Portrait Collection of the Royal Society of Medicine) 154
Fig 201 Chevalier Jackson (from *The Life of Chevalier Jackson* New York 1938) 155
Fig 202 Gustav Killian (*Acta oto-laryng* 1921 3 250) 156
Fig 203 Jean Jacques Joseph Leroy D Etoilles (Courtesy Wellcome Historical Medical Museum) 156
Fig 204 Rudolph Matas (*Amer J Surg* 1931 14 1) 157
Fig 205 Samuel James Meltzer (Kagen S R *Jewish Contributions to Medicine in America* 2nd edition Boston 1939) 157
Fig 206 Willy Meyer (*J Thorac Surg* 1931–32 1, 451) 157
Fig 207 Alexander Monro (Secundus) (Peck T W and Wilkinson, K D *William Withering of Birmingham* Bristol 1950) 158
Fig 208 Joseph O Dwyer (*Arch Pediat* 1896 13 404) 158
Fig 209 Paracelsus (from the Portrait Collection of the Royal Society of Medicine) 159
Fig 210 Alban Alphonse Ambroise Ribemont Dessaignes (from the Portrait Collection of the Royal Society of Medicine) 159
Fig 211 Ferdinand Sauerbruch (*Z Tuberl* 1951 99 58–59) 160
Fig 212 John Snow (*Asclepiad* 1887 4 274) 160
Fig 213 Friedrich Trendelenburg (Courtesy Wellcome Historical Medical Museum) 160
Fig 214 Theodore Tuffier (Mansch *Intellectual World*) 161
Fig 215 Andreas Vesalius (Pettigrew T J *Medical Portrait Gallery* Vol II London 1838) 161
Fig 216 Franz Volhard (Courtesy Dr D Volhard) 161
Fig 217 Max Wilms (*Münch med Wschr* 1918 65 709) 162

The Principles of Thoracic Anaesthesia

INTRODUCTION

THE practical solution of the many problems associated with surgery of the open chest is a comparatively recent event. For some twenty years before the opening of the present century many attempts had been made to operate within the thoracic cavity by surgeons already well versed in the abdominal surgery of that day. All without exception were hampered in their work and troubled in their minds by what has been termed the 'pneumothorax problem'.* Scarcely would the chest be opened but the lung would collapse, and the patient begin to make vigorous respiratory efforts, the mediastinal structures would move violently and the surgeon find it nearly impossible to operate. The patient would become cyanosed from anoxia due to inefficient respiration and this be further complicated by interference with the action of the heart, occasioned by the mediastinal movement. The condition of the patient would rapidly become worse and he would be liable to die if the chest were not closed without delay.

Various measures, mostly empirical, were tried through the years to obviate the dire effects of the large opening in the chest wall. One of these measures, for example, which was generally known as 'Muller's Handgrip', consisted of pulling out the lung through the wound immediately the chest was opened, and so, as it were, plugging the opening with lung. In another of 1895[3] the opening into the chest wall was kept so small that the exploring fingers blocked it nearly completely. The effect of the opening was thus nullified.

It was also noted that little trouble was encountered in cases where the lung was found to be adherent to the chest wall. So striking was the beneficial effect of an adherent lung in preventing pneumothorax difficulties that several surgeons attempted to provoke such adhesions if they were not already present, by injecting irritants into the pleural cavity some little time before attempting thoracotomy.

In the face of these comparatively simple safeguards it is little wonder that though thoracotomy was possible, the prognosis after major resections was extremely poor. Nevertheless, animal experiments and limited clinical experience showed that even by the employment of these means, lobectomy and pneumonectomy could not only be performed but that life was possible after such operations.

* The term pneumothorax was coined by the French physician Itard in 1803.[1]

For a proper understanding of the methods of anaesthesia which to day make possible the lengthy and involved operations upon the contents of the thorax, it is essential to have a clear conception of the problems which confront the anaesthetist in these circumstances If progress is to be made in this field it is advantageous, in addition, to be familiar with the evolution of practice and thought with regard to these problems during the last hundred years We propose, therefore, to discuss first the nature of the problems of anaesthesia during thoracotomy, and in broad outline how they may be solved A roughly chronological account then follows of the evolutionary process that led to present day methods

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PART I

THE PNEUMOTHORAX PROBLEM AND ITS SOLUTION

CHAPTER I

THE PROBLEM

IT had for long been known that life is incompatible with a large opening through the thoracic wall into the pleural cavity. But it was also known that the harmful effects tended to be proportional to the size of the opening. The smaller the opening the less the upset, until when quite small, an opening could be made into the pleural cavity with little upset to the patient[1] (see p. 6).

The collapse of the exposed lung

When the pleural cavity is opened to the exterior, the lung on that side, normally distended so that it comes into close apposition to the chest wall and mediastinal contents, is seen to fall away from the chest wall and to become much smaller although still expanding and contracting in a rhythmic manner with respiration. The now shrunken lung is about one third its normal size.

In order to understand why the lung collapses, the various forces acting inside and outside the lung must be considered.

Certain forces tend to keep the lung inflated, while others tend to the reverse. Of the former the main one is the pressure of the air in the alveoli. This is the same as the atmospheric pressure, for the alveoli are in free communication with the exterior. Another force[2] tending to keep the lung from collapsing, insignificant in magnitude compared to the atmospheric pressure, is the adhesion between the visceral and parietal layers of the pleura, due to the surface tension of the fluid which lubricates these layers. Such adhesion between these layers may often be demonstrated at operations. When a rib has been removed and the parietal pleura carefully exposed, the moving lung can clearly be seen in close contact with the transparent parietal pleura. A small incision may now be made in the parietal pleura without collapse of the lung. A little separation of the pleural layers, however, breaks the film of liquid, and the lung quickly falls away from the chest wall.

In normal life these two forces keeping the lung expanded are opposed only by the natural elasticity of the lung resulting from the pull of the elastic fibres of the interstitial tissue and the elasticity of the bronchial tree (Fig. 1). The so called negative pressure in the pleural space really represents the elasticity of the lung unsuccessfully trying to make the organ smaller. In the intact thorax the absolute magnitude of the intrapleural pressure is the

atmospheric pressure minus the retractive force of the lung When the pleura is opened, atmospheric pressure now acts on the outside of the lung,

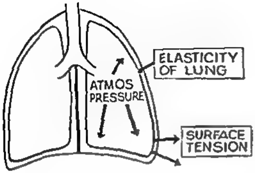
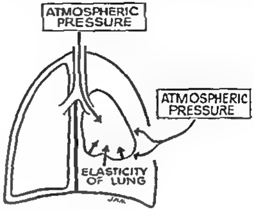


FIG 1



FIG

neutralizing that within the alveoli The sole effective force is the elastic retractibility of the lung itself, and the lung therefore collapses (Fig 2)

Mediastinum

Though the mediastinal structures divide the thorax into two halves, they are normally sufficiently elastic to make the behaviour of each half of the chest during respiration dependent on conditions in the other The capacity of each side of the thorax to function independently is determined by the degree of elasticity of the mediastinum When this is rigid as from disease, an opening into one side of the chest makes little difference to the pleural pressure and to the tidal volume of respiration on the other side, though paradoxical respiration occurs With a flexible mediastinum the presence of a pneumothorax on one side causes a marked movement of the mediastinum to the unopened side on inspiration On expiration the reverse occurs The effect of this movement of the mediastinum is to reduce, sometimes markedly, the volume of air entering the lung on the intact side at each breath

Paradoxical respiration

It is easy to observe when looking through a thoracotomy opening, that when the patient breathes spontaneously the collapsed lung expands and contracts in a rhythmic manner Closer observation will show that unlike the normal state of affairs, the observed lung becomes smaller on inspiration and larger on expiration This is the paradox

On inspiration the whole thorax enlarges and the extra space is occupied by the entry of air into the lungs and of blood into the heart from outside

the thorax In the intact subject the air enters the thorax through the trachea, and each lung receives an addition of fresh air In the presence of a thoracotomy opening, air enters the thorax not only through the trachea into the alveoli, but also through the thoracotomy opening into the space around the exposed lung The amounts of air which pass through each of these depends on the relation between the cross-section area of the trachea and that of the thoracotomy opening On inspiration, therefore, there is a competition, so to speak, between the air entering the thorax down the trachea and that through the chest wall opening With a large opening in the chest wall, the greater amount of air enters the thorax through this, and the mediastinum is pushed to the limit of its flexibility towards the unopened side

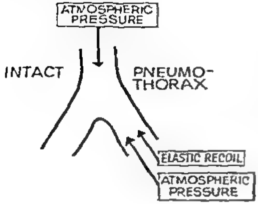


Fig 3

During inspiration the air pressure in the bronchus of the exposed lung is greater than that in the trachea, since to the atmospheric pressure is added the elastic recoil of the lung (Fig 3) The increase in size of the intact half of the thorax on inspiration is satisfied by air which comes first from the exposed lung and secondly from the trachea and exterior On inspiration, therefore, the exposed lung becomes smaller

On expiration the reverse procedure occurs The thorax becomes smaller in size On the side of the pneumothorax the air lying outside the lung is freely discharged into the exterior through the thoracotomy opening On the other side air is discharged partly into the trachea and partly into the exposed lung The latter therefore becomes larger on expiration and smaller on inspiration, and the mechanism of paradoxical respiration is explained

Why is paradoxical breathing harmful?

When the exposed lung becomes smaller on inspiration, the air discharged from it passes into the unexposed lung The air, therefore, that enters the lung on the intact side comes partly from the trachea and hence from the outside and partly from the exposed lung Paradoxical respiration thus means a transfer of air from one lung to the other at each breath, and this has been somewhat picturesquely but aptly named pendulum air *

The bigger the thoracotomy opening in relation to the tracheal opening the greater will be the proportion of pendulum air in each breath entering the lung on the intact side This circumstance not only occurs when the size

* The pendelluft of Brauer

of the thoracotomy opening is large, but also when the trachea is reduced in size by an obstruction and the size of the thoracotomy opening is relatively increased.

Paradoxical breathing is increased in extent by respiratory obstruction and by vigorous respiration. It is clear, therefore, that in order to minimize paradoxical respiration the anaesthetist must ensure a perfect airway and the gentlest and quietest respiratory activity consonant with adequate ventilation. Coughing, for example, by increasing the intrapulmonary pressure behind a closed glottis causes very marked paradoxical movement.

From the point of view of oxygenation the harm that results from paradoxical respiration is obvious. Fresh air mainly enters one lung only and even this one does not expand as fully as it does normally. Of that expansion, part only is due to the ingress of fresh air, the rest being air from the opposite lung.

Other harmful effects of paradoxical breathing are the reduction in the suction effect of natural breathing in aiding the return of blood to the heart. With decreased filling of the heart the output falls. The movement or 'flapping' of the mediastinum which accompanies paradoxical breathing initiates reflex circulatory phenomena which, if in sufficient degree, present as the clinical syndrome of shock. The mechanism whereby marked movement of the mediastinum sets up the reflexes leading to shock is not well understood. From the analogy of shock occurring during cardiac operations when the heart is rotated on its long axis, it may be that mediastinal movement during paradoxical breathing rotates the heart somewhat in a similar manner.

That the shock in these circumstances is reflex is shown by the good effects which have been reported following infiltration of the pulmonary plexuses at the hilum of the lung or of the vagus nerves in the neck with local anaesthetic.

The mediastinum is sometimes fixed by disease and in these circumstances the movement during thoracotomy and paradoxical respiration is small in extent, and as clinical experience shows, shock is not so likely to occur. Also, when the patient is so placed that he lies on the opened side the effects of paradoxical movement are minimized, because the mediastinum is kept towards the opened side by gravity[4] (see also p. 136).

The patient with a large thoracotomy opening, and who is breathing spontaneously suffers, therefore, from increasing asphyxia, poor return of blood to the heart, and shock, each of these initiating and mutually strengthening their own vicious circle of events.

In addition to these serious physiological upsets, paradoxical respiration is also believed to be the means of spreading infection from one lung to the other, an occurrence to be dreaded at any time, and particularly during resection for tuberculosis.

Complications added by disease in the lungs

Decreased ventilatory capacity

The state of affairs which has been described, occurs when a healthy subject has his chest opened. The patient who comes to operation suffering from some intrathoracic disease often presents certain complicating factors. A varying amount of lung tissue may be diseased and non functioning, and without certain precautions a thoracotomy in such a patient may be rapidly fatal, for the ventilatory capacity is an important factor affecting his capability to withstand operation.

The healthy patient tries to neutralize the ill effects of a pneumothorax by increased respiratory effort, and if his vital capacity is large enough and the hole in the pleura is small, the anoxia may be prevented. As the vital capacity becomes smaller the ability to compensate decreases and when the size of the vital capacity approaches the tidal air there is little room for compensation and any hole in the pleura, however small, may produce the gravest effects.

Secretions

Sputum and pus may be present in the bronchial tree, and these may not only be an obstruction to respiration, thus heightening the degree and effect of paradoxical breathing and increasing the risk of asphyxia, but they may also spread disease to healthy parts of the lungs.

In the conscious state these secretions are mainly removed from the bronchial tree by coughing aided by ciliary activity. Little wonder, then, that until recently it was believed that the retention of the cough reflex was a vital requisite for safety during thoracic operations. During coughing, however, the larynx is closed and a high intrapulmonary pressure built up. With an open chest the pressure rise causes great inflation of the exposed and unsupported lung. Thus are produced the most violent examples of paradoxical movement, since in these circumstances of closed glottis and raised intrapulmonary pressure, the unexposed lung empties itself into the exposed lung, causing it to balloon up in the most alarming manner before the surgeon's eyes. After the cough the following sharp inspiration empties the exposed lung in an equally striking manner, and paradoxical movement of the most turbulent and severe type occurs. Coughing during a thoracotomy not only makes the operation virtually impossible for the time being, but if allowed to persist quickly reduces the patient to a state of asphyxial collapse.

Operative stimuli

A third complicating factor during a thoracic operation is the presence of operative stimuli. These stimuli applied to the hilum of the lung, the bronchi,

and the pulmonary tissue produce reflex disturbances in the shape of broncho spasm, outpouring of secretions and coughing, all of which heighten the other harmful effects of thoracotomy Bronchial spasm, for example, may lead to a state of extreme anoxia in the space of a few minutes, while falls in blood pressure and cardiac irregularities are well known sequelae to rough handling of the hilum

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SOLUTIONS OF THE PROBLEM

THE largely physical problems of overcoming the effects of thoracotomy have been solved partially or wholly in a number of ways All these solutions are still in use in one form or another in different parts of the world, in Britain, the United States and Scandinavia only controlled or assisted respiration, and to a very minor extent positive pressure anaesthesia, remain

Positive pressure breathing

At first, attention was directed to preventing the collapse of the exposed lung, then believed to be the main cause of the associated asphyxia It seemed to the early observers that so long as the lung was well expanded all was well The lungs of a dead animal may be inflated easily by raising the air pressure in the trachea so, too, may those of the living one If the air pressure in the trachea and lungs is maintained above that of the atmosphere, the exposed lung will keep distended though the chest be open If the difference between the pressure in the trachea and that of the atmosphere is not too great, breathing continues spontaneously Paradoxical respiration, however, occurs in the same manner as described on page 5, though the extent may seem less

Fig 4 shows what happens when the pressure of the inspired air is raised

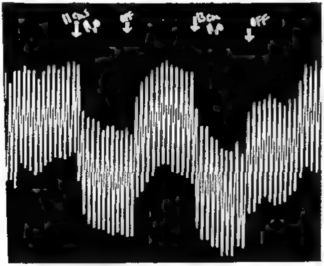

FIG 4

above atmospheric The spirometer tracing was taken during spontaneous respiration at atmospheric pressure At the points marked, the pressure is

increased by placing a weight on the spirometer The lungs quickly distend a little and then breathing carries on as before The lungs, however, do not collapse to the same extent at the end of each expiration The increase in pressure has increased the functional residual air and, therefore, the physiological dead space [1, 2]

There comes a point when, with increasing pressure, asphyxial symptoms appear even though spontaneous breathing is maintained With the less complete emptying of the lung at the end of each breath, the tidal volume decreases and both the oxygen supply and the carbon dioxide clearance are correspondingly reduced It is interesting to read that those who advocated positive pressure breathing of this sort for anaesthesia during thoracotomy, advised[3] that every few minutes the pressure should be reduced and the lungs allowed to collapse (see also p 64) The correctness of this advice, initially based on experience, has been confirmed experimentally in more recent years, and it is clear to us now that serious carbon dioxide accumulation may easily occur in the presence of normal arterial oxygenation [4, 5]

Positive pressure breathing in the manner described was used as one way of overcoming the collapse of the exposed lung during thoracotomy (Fig 32, p 51), though the lung may be kept distended to any desired degree, paradoxical movement, however, persists (Fig 7)

When the positive pressure is increased beyond a certain degree efficient breathing becomes impossible If the patient is to live in these circumstances the pressure must be released, so that the accumulated carbon dioxide may be removed and sufficient oxygen reach the alveoli

A simple way of producing positive pressure for this technique is to use an expiratory valve, the loading of which can be varied A continuous stream of gases from cylinders is run into the apparatus, and the expiratory valve adjusted so that at the height of expiration the desired pressure is reached in the respiratory tract Such a valve is exemplified by the now common spring loaded type Better still is the simple valve consisting of a tube dipping under the surface of water (Fig 5)

By varying the depth 'h' of the tube under the water the expiratory pressure may be increased to any desired and known extent These water valves were often placed on the floor so that although a positive pressure of, say, 2–4 cm of water was required before gas escaped it was almost impossible for the patient to suck the water into the face mask Such a valve becomes, in effect, an efficient one way valve

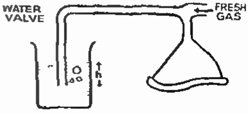

Fig 5

Anaesthesia conducted by this method is obviously difficult to maintain if secretions are to be removed by suction It seems from the literature that

in the days when this method was the popular—in fact, almost the only one in use—surgeons and anaesthetists were not so much concerned with the removal of secretions as the removal of vomit (Fig 49)

Positive pressure anaesthesia remained the accepted method up to 1937 [6] Its persistence until as late as this was due not only to the advocacy of such powerful authorities as Sauerbruch but also to the seeming unawareness of more effective methods, which had already been published many years before (see p 78) The disadvantages of the positive pressure method had already been clearly pointed out by Giertz in 1916,[7] who showed not only that ventilation was inadequate but that with it carbon dioxide retention occurred, oxygenation was interfered with, filling of the heart was poor and that a general interference occurred with the venous return to the heart and the efficiency of the circulation It was also apparent that patients became fatigued in trying to expire against a heavily loaded valve and that the distended lung was more a nuisance than a help to the surgeon Also, secretions may be blown into the terminal bronchioles,[8] leading to the occurrence of atelectasis Venous pressure is raised causing increased oozing and haemorrhage (see also pp 53, 64) The venous pressure rises in direct proportion to the pressure transmitted to the heart A 15 mm Hg rise in intrapulmonary pressure causes a 70 per cent increase in venous pressure [9] The rise in venous pressure during positive pressure breathing leads to venous congestion, obvious not only in the reddened and blotchy skin of the patient, but also in the free bleeding during the operation

Negative pressure breathing

This method differs only in degree from the positive pressure method The difference in pressure between the gases in the trachea and lungs, and the atmosphere surrounding the exposed lung, is produced and maintained by enclosing the body of the patient, but not his head, in a chamber in which the pressure is below that of the atmosphere (Fig 30, p 50) Since such a chamber must be large enough to accommodate the surgeon and his assistant, the method never became more than of passing and historical interest

Both the positive pressure and the negative pressure methods may be designated as differential pressure anaesthesia In both of them a pressure difference is maintained between the air in the lungs and the air surrounding the exposed lung Since, however, one pleural cavity is intact and the diaphragm continues to maintain spontaneous respiration, paradoxical movement still continues The magnitude of the optimum differential pressure is similar to that which exists in ordinary life, that is, the negative intrapleural pressure If the differential pressure is greater than this the exposed lung inflates beyond the limits of the thoracotomy opening If it is less, expansion of the lung is less than normal The differential pressure both

in the case of these methods of anaesthesia and in normal life represents the force of the elasticity of the lung

Insufflation

In this method a catheter, generally with a bore rather small compared to the trachea, is inserted down to the carina and a constant stream of gases blown through it, so that a pressure of about 10–20 cm H_2O is registered in the manometer on the apparatus The gases escape to the exterior between the tube and the trachea In streaming out to the exterior, the gases carry with them the carbon dioxide from the lungs The oxygen in the gas mixture (usually air is the main component) is blown into the bronchi and diffusion as well as respiratory movements carry it to the alveoli The good oxygenation and carbon dioxide removal, and the reduction of the physiological dead space to a fraction of the normal, quickly makes spontaneous breathing very shallow, and on occasions the patient's breathing may appear to be at a stand still Nevertheless, in spite of poor or even absent respiratory movements, oxygenation remains excellent Here, too, as with positive pressure breathing, it became the practice to interrupt the flow at regular intervals and to allow the lungs to collapse If this is not done, cyanosis and impairment of the circulation may gradually appear (p 64) It can be seen that in effect the continuous insufflation of gases into the trachea is a variation of the positive pressure method, with the difference that dead space is reduced and better carbon dioxide clearance effected

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CHAPTER III

CONTROLLED RESPIRATION

Control of secretions

As the scope of thoracic surgery increased and the immediate danger to life of opening the thorax was reduced, attention began to be given to the problem of dealing with secretions in 'wet' cases. There was a striking absence of reference to this problem by the earlier surgeons. As late as 1937 the opinion was expressed that, 'Aspiration of infected contents from the bronchial tree has greater theoretical than practical advantages.'[1] For some twenty to thirty years before World War II the retention of the patient's own cough reflex as a means of getting rid of secretions was considered essential. This meant that if general anaesthesia was used, the lightest level, with its attendant difficulties of reflex movement and vomiting, was desirable. More than one anaesthetist advocated regional or spinal block for these operations, solely with the retention of an 'active' cough reflex in mind.[3, 4]

A great step forward was taken when it was realized that coughing during thoracotomy was not only inefficient in expelling secretions, but resulted in a turbulent operative field, with exaggerated paradoxical breathing, in which it was often impossible for the surgeon to work. With this realization came the use of catheters passed into the trachea to remove secretions by means of mechanical suction (see pp. 122, 129).

Rhythmic inflation

With light anaesthesia no longer needed for the retention of the cough reflex, came the rediscovery of the comparative ease with which apnoea can be induced. Guedel, like Janeway before him in 1906, discovered in 1934[5] that a combination of deep anaesthesia and hyperventilation by the anaesthetist squeezing the bag, soon brought breathing to a standstill. Experience reassured his dubious colleagues that this state of affairs need give rise to no anxiety, so long as the patient's lungs were rhythmically inflated by squeezing the reservoir bag of a carbon dioxide absorption apparatus.

Guedel used this method during abdominal and similar operations where control of the depth of breathing and of the movements of the viscera would be of assistance to the surgeon. Gradual realization came that in this technique lay the solution of the problem of obviating the harmful effects of thoracotomy, for the abolition of the cough reflex, so important for a tranquil operating field, could now be more than offset by the use of mechanical

suction to remove secretions.[6] Paradoxical breathing was abolished by the induction of apnoea and life was maintained by rhythmic and controlled inflation of both lungs simultaneously, irrespective of the size of the thoracotomy opening. All that was essential was a perfect air-way between reservoir bag and alveoli; it became common practice to ensure this by the insertion of a large calibre endotracheal tube. For the conservation of an expensive gas like cyclopropane, and to eliminate leakage between tube and trachea, the incorporation of an inflatable cuff on the tube was usual.

Most of the advocates of spinal and similar methods of anaesthesia sooner or later changed their method, some, in fact, acknowledging the poor results they had had with spinal anaesthesia.[7] During regional anaesthesia the diaphragm remains active and though its activity is lessened by the depressed and quiet breathing of opiate medication, paradoxical movement, mediastinal shift and the troubles associated with voluntary coughing still occur.

Inflation pressures

The elasticity both of the lungs and of the thoracic cage must be overcome before the thorax enlarges and the lungs inflate. The pressure required to overcome the elasticity of the lungs is, in fact, equal to the difference which normally exists between the pleural and pulmonary (that is, atmospheric) pressures. This pressure may be as little as 5–10 cm H_2O. To enlarge the thoracic cage requires a pressure varying from 1–2 cm H_2O in an infant to as much as 20–30 cm H_2O in an elderly patient with a rigid cage.

Once the chest wall is opened the lung on that side is free to expand without any coincident enlargement of the thoracic cage. The bag pressure required, therefore, is now much less than before the chest was opened.

In clinical practice, before the chest is opened, an inflation pressure of, say, 25 cm H_2O or more is needed for efficient ventilation. Once the chest is opened widely, 10 cm H_2O may suffice for ample expansion of the lungs. Extra pressure may be required if the lung is hindered from expanding by the surgeon's fingers or by the use of retractors.

The usual method of inflating the lungs is by squeezing a thin-walled rubber bag. By using one or two hands in the ordinary way, the maximum pressure reached is rarely more than about 20–30 cm H_2O because at that level the rubber stretches without further rise in pressure. If the bag material is of other than the thinnest rubber, or if there is a possibility that pressures in excess of 30 cm H_2O are likely to be generated, a simple safety blow-off valve of the pattern shown in Fig. 5 should be used.

In connection with the possible risks attendant on the use of manual squeezing of a bag for inflation of the lung, it should be noted that a normal subject can without difficulty produce a pressure of about 100 mm Hg (140 cm H_2O) in the lungs on coughing or straining. It seems unlikely, except

in those with abnormalities such as subpleural emphysematous bullae, that pressures up to 20 cm H_2O in the lungs will do much harm

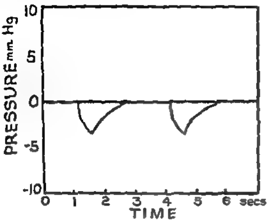

FIG 6 Pressure Curve Normal Breathing

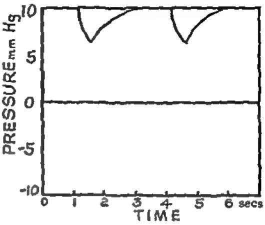

FIG 7 Pressure Curve Spontaneous Positive Pressure Breathing

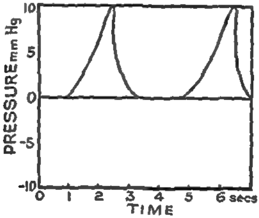

FIG 8 Pressure Curve Controlled Respiration

During 'controlled respiration' the pressure inside the lungs varies between atmospheric and little more than + 10 cm H_2O The pressure never, as during spontaneous respiration, falls below atmospheric Reference to Fig 6 shows that during spontaneous respiration the intrapulmonary pressure varies slightly between atmospheric and a few cm H_2O below that The lowest pressure is at the height of inspiration The reverse is the case in controlled breathing (Fig 8), the pressure is always above atmospheric, being greatest at the height of inspiration This may have some effect on the blood flow through the alveolar vessels since the blood pressure in them is very small indeed It is for this reason that the peak of inspiration during controlled breathing should be kept as short as possible, and prolongation of this peak avoided When squeezing the bag, as soon as the desired compression has

been effected, the hand should be opened smartly and the lungs allowed to empty freely

So long as the lung is not inflated beyond the limits of the thoracotomy opening, the differential pressure is not in excess of that normally present during the life of that individual Excessive pressure is indicated by expansion of the lung beyond the limits of the chest wall opening

Once the chest wall has been opened the mobility of the mediastinum allows expansion of the unexposed lung without necessarily any accompanying enlargement of the thorax

Advantages of controlled respiration

1 Paradoxical breathing is abolished and adequate oxygenation and carbon dioxide clearance ensured

2 The mediastinum is centralized and both it and the diaphragm no longer move in a manner disturbing to the surgeon

3 The moving lung can be controlled at will so that at any moment, when the operation demands, movement may be reduced till the lung is at a standstill

4 The good ventilation ensures ease in maintaining the desired depth during inhalation anaesthesia

5 Since the work of respiration is expended by the anaesthetist's hands, the patient's muscles are rested and the oxygen need, in general, reduced

6 Much information regarding the depth of anaesthesia is derived by the anaesthetist from the 'feel' of the bag during inflation The bag pressure required to produce adequate inflation increases in proportion to the muscular tone of the patient

Disadvantages of controlled respiration

The possibility of rupture of alveoli is remote, unless a condition like bullous emphysema is present Injury to the alveoli is probably no more likely to occur during controlled respiration with the common thin rubber anaesthetic bag, than during normal life

The positive pressure in the lungs at the peak of each inspiration has the same effect in reducing the cardiac output, though to a less extent, as continuous positive pressure breathing (p 12) For this reason it is important, not only to release the pressure at the height of inspiration quickly to atmospheric, so that the lungs can collapse to the fullest extent, but to allow a sufficient pause between each inflation for a large enough number of normal heart beats to make up for the impaired output during the inspiratory periods [8, 9]

Other reputed disadvantages are the possibility that hyperventilation might lower the carbon dioxide content of the blood—though experimental

observations show this to be extremely unlikely—and also the difficulty the anaesthetist might have in assessing the depth of anaesthesia, when the patient is apnoeic The feel of the bag and, in the case of certain anaesthetics, a sniff at its contents, combined with the usual careful observations of the patient in general, give all the information the experienced anaesthetist requires In connection with the possibility of acapnia occurring through excessive ventilation, the opinion, based on experiments, has been recently expressed[10 11] that the prolonged apnoea in these circumstances might be due not so much to a combination of hyperventilation and respiratory depression as to reflex inhibition of the respiratory centre as a result of the distension of the lungs

The danger of further impacting plugs of sputum into the bronchi has already been mentioned

In certain circumstances controlled respiration may be inadvisable The anaesthetist may not have the equipment necessary although this may be no more complicated than a face mask, canister of soda lime, bag and a supply of oxygen Though, in general, the circulatory changes during controlled respiration are so small as to be hardly detectable, they may be of moment in a patient already severely shocked Even so, the method may offer the best chance of success if his chest is to be opened, no other method will give such good oxygenation and carbon dioxide clearance Controlled respiration should be used with caution when no endotracheal tube is in place Dilatation of the stomach with anaesthetic gases is almost certain, and to avoid the consequent discomfort to the patient and the interference of a dilated stomach to the surgeon in operations near the diaphragm, it is better to have an endotracheal tube in place connected to the anaesthetic apparatus whenever controlled respiration is to be used In the days of continuous positive pressure anaesthesia acute dilatation of the stomach was a well known immediate post operative complication [1]

A patient known to have bullous emphysema or a cyst such as described on page 20 is better left to breathe spontaneously until the chest is opened, when the effect of inflation can be seen and corrected if necessary

Trilene and soda lime must not be used together Therefore controlled respiration with a bag on an absorber is contra indicated in the presence of this anaesthetic

Assisted respiration

This term is given to the procedure in which the patient is allowed to breathe spontaneously, every breath or so being augmented by the anaesthetist squeezing the breathing bag Opinion at the moment is somewhat divided on whether assisted respiration by no means easy to carry out successfully over long periods of time has any advantage over controlled

respiration. The advocates of assisted respiration claim that the method lessens the likelihood of hyperventilation and the production of acapnia, that it reduces the danger of anaesthetic overdose, and that it minimizes the circulatory upset, small though it is.

The importance in practice of these points *is doubtful*. *In any case*, when assisted respiration is attempted, as often as not, the anaesthetist finds himself before long doing controlled respiration, the patient having quietly stopped his voluntary efforts.

Broncho pleural fistula

This is a communication between the respiratory tract and the pleural cavity. It may be present before the operation or it may be produced during the operation. Its size may vary from almost microscopic punctures, such as occur so often when, for example, the visceral pleura is stripped off the lung, to the full section of a main bronchus close to the trachea. The dangers of a fistula during thoracotomy are two.

1. *Interference with ventilation.* When the lungs are inflated a portion of the gases squeezed out of the bag into the trachea escape through the fistula. *The volume of gas which escapes through the fistula is of little interest.* What is important is that sufficient gases should still enter the lungs and that ventilation of them be adequate. To compensate for the presence of a fistula a large enough volume of gas must be forced into the trachea so that in spite of the escape through the fistula, adequate ventilation of the lungs occurs. In the case of alveolar or small bronchiolar fistulae little alteration in technique is needed. The anaesthetist may even be unaware that such a fistula is present until his attention is directed to it by the hiss of escaping gas or by his surgical colleague. In the case of a large fistula such as occurs, for example, when a main bronchus is cut across, grave anoxia quickly develops unless energetic measures are taken to provide adequate ventilation. Gas flows of 20 or more litres per minute combined with vigorous bag squeezing producing pressures of, say, 25–30 cm H_2O may be required to minimize the presence of such a large fistula.

It must be obvious that it is highly dangerous to use diathermy in the presence of a fistula when an inflammable anaesthetic is in use. More than one explosion has occurred in recent years in these circumstances. Not even an intact pleura between fistula and diathermy needle gives protection.[13,14] Nowadays, the use of explosive anaesthetics like cyclopropane and ether is being displaced by techniques in which combinations of nitrous oxide, analgesics and relaxants form the basis.[illegible]

2. *Entry of pus and blood into the respiratory tract.* This perhaps constitutes an even greater danger than the first. The fistula may communicate with an empyema or an abscess cavity and the anaesthetist may be faced at any time

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2 *Entry of pus and blood into the respiratory tract* This perhaps constitutes an even greater danger than the first The fistula may communicate with an empyema or an abscess cavity and the anaesthetist may be faced at any time

with a sudden and unexpected flooding of the respiratory tract with pus This may even occur within a few moments of starting the anaesthetic

The prevention of this calamity is clear These patients should always be kept in such a posture that the fistula is above the fluid level in the abscess or empyema cavity For example, drainage of an empyema is commonly performed with the patient in a half sitting position, so that if a fistula is present, decanting of the pus into a bronchus is unlikely During the operation blood easily, and often without being suspected, enters the respiratory tract through a fistula The blood quickly clots and cannot then be removed by suction Such flooding is to be feared because once it has occurred little can be done to overcome its effects At best an atelectatic area with a stormy convalescence follows, at worst, if the flooding is extensive, the patient may die, with the anaesthetist and surgeon almost powerless to prevent it

The prevention of these dire happenings lies mainly in the use of frequent and vigorous suction by means of a catheter inserted as low into the respiratory tract as possible The greatest care should be exercised by the surgeon also to prevent blood from entering any fistulous opening present This care is particularly needed when the fistula is perhaps a rather small bronchus in the middle of an oozing operative field Any fistula should be closed as soon as possible

Should a really large flooding take place from an abscess cavity or an empyema in the middle of an operation, suction alone may not be able to remove the fluid quickly enough and the operating table should be tilted so that the secretions may run down the trachea to the exterior as well The previous insertion of a bronchus blocker wherever practical is a great safeguard in any patient in whom the problems associated with a fistula are likely to occur

A dangerous state of affairs may exist in the rare case of a cyst, usually large, of the lung communicating with a bronchus The communication is often valvular so that on inflation the cyst is distended without reduction in size during deflation Compression of the surrounding lung occurs If the condition is unsuspected by the anaesthetist during the induction of anaesthesia, the more energetic his attempts at resuscitation by inflation, the more the lungs are collapsed by the increasing distension of the cyst Rapid asphyxia and death of the patient results unless the chest is quickly opened and the lungs allowed to expand In these cases the need for inflation of the lungs should be carefully avoided until the chest is opened, relaxants and respiratory depressants are therefore contra indicated during induction of anaesthesia [18]

Automatic devices

The monotony of rhythmically squeezing a bag for long periods of time may not only be apparent but sometimes is real The anaesthetist may also

need to have his hands free for such things as setting up a transfusion, taking blood pressures and generally looking after the patient Sometimes there is uncertainty that the one at the head end of the patient has the required skill and knowledge to carry out manually controlled respiration These considerations have been responsible for the introduction of mechanical devices for maintaining controlled respiration

The use of these forms of apparatus may be attended, however, with certain grave disadvantages First and foremost, the information which the anaesthetist s hand gains from contact with the breathing bag is lost Very much information, indeed, is obtained during the process of squeezing the bag The amount of effort necessary to produce the desired pulmonary inflation gives information about such things as the level of anaesthesia, easier inflation means relaxation of the respiratory muscles and therefore deeper anaesthesia or more complete curarization The presence or otherwise of conditions like bronchospasm and respiratory obstruction may also be indicated in this way The volume exchange that occurs when the bag is squeezed with a particular manual effort is another valuable piece of information The hand, too, feels transmitted to the bag every flicker of the diaphragm, and every attempt at coughing By looking at the bag between inflations the volume changes due to the heartbeat can easily be seen Manual squeezing of the bag is noiseless, there is little mechanical to go wrong, dangerous pressures are unlikely to be generated and the only, and not unreasonable, requirement for efficient operation is the presence of the anaesthetist

It must be admitted, however, that frequently for the major part of an operation the rhythmic squeezing of the bag may be a tedious and monotonous procedure, and there are times when a mechanical device is most helpful, even if only to take over for short periods of time when the anaesthetist wishes to have his hands free

Some criteria for a satisfactory mechanical, rhythmic inflator

1 Any electric motor in the apparatus must be hermetically sealed Otherwise the motor should be situated outside the operating theatre The risk of explosion is thus minimized by lessening the chance of contact between explosive vapours and sparking brushes The more silent the motor the better

2 The peak pressure developed within the lungs at the height of the inspiratory cycle must be within the control of the anaesthetist and the possible range of such pressures should vary from atmospheric to +25 cm H_2O

3 A safety valve must be provided which will blow off at any predetermined pressure within the range of atmospheric to +25 cm H_2O This valve will safeguard the patient s respiratory system should a mechanical fault develop and high pressure be generated

4 The fluctuations of pressure during controlled respiration can never

be the same as during natural breathing Nevertheless, in certain ways the two processes should resemble each other The pressure differential between the inside and the outside of the lungs should be the same The rate of inflation of the lung, and therefore of change of pressure within it, should be the same in controlled as in spontaneous respiration In particular, the peak of inspiration should be sharp and not prolonged (see Figs 6 and 8)

5 Should the patient make attempts to breathe himself, the machine should pick up the patient's rhythm, and not carry on its own rhythm in defiance of the patient's breathing activity

6 The change of cycle from inspiration to expiration should occur without lag as soon as the predetermined maximum pressure has been reached At this point the pressure in the lungs should fall rapidly to atmospheric so that the lungs deflate passively at their own rate

7 Within reasonable limits there should be control over the length of expiration, so that the pause between the end of expiration and the beginning of inspiration may be varied at will The same applies to the length of inspiration

8 The device should be capable of delivering a sufficiently high peak flow rate (at least up to 60 litres per minute) at the height of inspiration, to cope with rapid rates of respiration

9 The device must be mechanically sound and capable of withstanding constant use without breaking down

The few machines of this sort on the market at the moment each have their own shortcomings It is likely that a technique combining manual squeezing of the bag with the occasional use of a mechanical device will be found of most value (Examples of automatic inflating machines will be found on pp 86–102)

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CHAPTER IV

CLOSURE OF THE CHEST WALL

CLOSURE of the chest wall after a thoracotomy inevitably leaves the patient with a pneumothorax since it is nearly impossible to remove all the air before the last stitch is inserted Some degree of pulmonary collapse always exists at this stage This means a reduction in the patient's respiratory efficiency, and a delay in his return to full respiratory activity until the pneumothorax has been absorbed and the lung expanded This delay may be serious after an operation in which functioning lung tissue has been removed and the ventilatory capacity of the patient reduced The pneumothorax must be abolished and the lung fully expanded at the earliest possible moment

The following methods have been employed to minimize the pneumothorax left at the end of the operation

Inflation of the lung during pleural closure

The chest wall is closed until only a small opening remains The bag is squeezed and the inflated lung held against the chest wall until the latter is completely closed This method entails a prolonged peak pressure in the lung, and the final closure of the chest wall is carried out by the surgeon under duress of time Experience has shown that air-tight closure of the chest wall may not occur until all the layers right to the skin have been sutured A variation of this method practised by some is to suture the chest wall round a small catheter in the pleural cavity When the closure of the chest wall and skin is complete, the lungs are inflated and, at the peak of inflation, the catheter is pulled out rapidly, the skin having been sutured tightly in the hope that air will be prevented from getting back along the catheter track

These methods are inapplicable when a drainage tube is to be left in the chest and in any case are not very efficient judged by post operative radiological appearances

Suction during or after closure

In this method a catheter connected to a suction apparatus is inserted into the cavity, and suction maintained until the wound is closed The catheter is pulled out at the end Alternatively, the chest is completely closed and a wide bore needle connected to a suction apparatus is thrust into the pleural

cavity and suction continued until an attached manometer shows that a negative pressure of some 8–10 cm H_2O is present in the pleural cavity. This method makes no allowance for temporary blockage of the needle or catheters by the lung giving a false impression of the intrapleural pressure.

Closure with intrapleural catheter and water seal

A tube is inserted into the pleural cavity through a separate stab hole, and the main wound closed. The tube is then connected up as shown in Fig 9. The tube is inserted about 2.5 cm under the surface of the water in a bottle whose diameter is not less than 15 cm. The glass tube inside the bottle has a diameter not less than 0.5 cm, so that little effort by the patient is required to expel the air from the pneumothorax out of his chest. When closure of the chest has been completed, inflation of the lungs or even spontaneous respiration by the patient pushes air out of the chest cavity because the air has only to overcome a resistance of 2.5 cm of water. The resistance offered by the glass tube in the bottle is negligible. However, if the bottle is kept on the floor, no air or water can be drawn back into the chest during inspiration because, in order to do so, the patient would have to lift water up a distance of say 1 metre. No effort of the patient can do this. The 'water seal,' in fact, forms a one-way valve. It allows air to leave the chest whenever the intrapulmonary pressure rises above +2.5 cm H_2O. It prevents air from entering the chest since intrapleural pressures of −1 metre of water do not occur. The bottle must be of large diameter, so that however high the water rises in the tube when the patient inspires, the end of the tube dipping into the water will not be uncovered. The tube diameter should be on the large

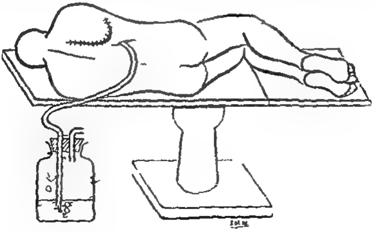

FIG. 9

side so that resistance to the flow of air through it is minimal. Needless to say, the bottle must, at all times, be kept 80–100 cm below the level of the

patient's chest. Lifting the bottle higher than this may be disastrous since, with a vigorous inspiration, some of the water from the bottle may be sucked into the pleural cavity.

An explanation of the simple principles on which the water seal depends should be given to every doctor and nurse who has charge of such patients. It is customary to mark the initial level of the water with a piece of strapping, so that the amount of blood or other liquids which emerge from the chest can be measured. The tube in the patient's chest may be removed within a short while after completion of the operation, or it may be left in place for one or more days until the lung is fully expanded. As soon as the patient breathes spontaneously after the operation, water will be seen to rise and fall inside the tube in the bottle. On inspiration the water rises, and on expiration it falls. The intrapleural pressure remains below atmospheric, except when, during coughing or forced expiration, some air is pushed out of the pleural cavity, or when a bronchopleural fistula is present.

When the lung occupies the whole of the hemithorax the difference in pressure in the pleural cavity between inspiration and expiration is small, say, 1–2 cm H_2O. When, however, as after resection, or when atelectasis is present, the contents of the hemithorax do not fill the space designed for it, large fluctuations in pressure occur on breathing. Inspection of the water seal therefore provides valuable information as to the degree of expansion of the lung. The amplitude of fluctuation indicates the difference between the volume change of that side of the chest and the volume change of the lung. The greater the amplitude, the poorer is the expansion of the lung.

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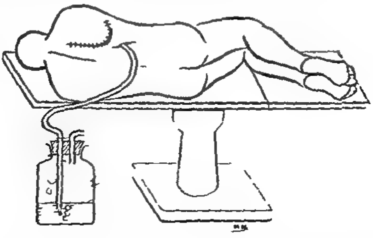

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PART II

HISTORICAL BACKGROUND

hold of them with one Hand and holding my other on his Breast at the left Pap, I blew again my breath as strong as I could, raising his Chest fully with it, and immediately I felt six or seven very quick Beats of the Heart, his Thorax continued to play and the Pulse was felt soon after in the Arteries.

To Paracelsus in the sixteenth century belongs the credit of inflating the lungs with a bellows connected to a tube inserted into the mouth of the asphyxiated patient. His method was taken up by Vesalius a little later to keep animals alive while demonstrating their anatomy. The illustration[5] (Fig. 10) taken from the latter's book, *De Corporis Humanis Fabrica*, published in 1555, shows a preliminary tracheotomy being performed.

In the words of Vesalius:

That life may in a manner of speaking be restored to the animal, an opening must be attempted in the trunk of the trachea, into which a tube of reed or cane should be put; you will then blow into this, so that the lung may rise again and the animal take in air. Indeed with a slight breath in the case of this living animal the lung will swell to the full extent of the thoracic cavity, and the heart become strong and exhibit a wondrous variety of motions.[6]

In 1667 before the Royal Society, of which he was curator, Robert Hook read a paper entitled:

An Account

Of an Experiment made by M. Hook, *of Preſerving Animals alive by Blowing through their Lungs with Bellows.*

This Noble Experiment came not to the Publiſher's *hands, till all the preceding Particulars were already ſent to the Preſs, and almoſt all Printed off (for which cauſe alſo it could not be mentioned among the* Contents); *And it might have been referred for the next opportunity, had not the conſiderableneſs thereof been a motive to haſten its Publication. It ſhall be here annexed in the Ingenious* Author *his own words, as he preſented it to the* Royal Society, Octob. 24. 1667. *the Experiment it ſelf having been both* repeated *(after a former ſucceſsful trial of it, made by the ſame hand a good while agoe)* and *improved the week before, at their* publick Aſſembly. *The Relation it ſelf follows.*

I Did heretofore give this *Illuſtrious Society* an account of an Experiment I formerly tryed of keeping a Dog alive after his *Thorax* was all diſplay'd by the cutting away of the *Ribbs* and *Diaphragme*; and after the *Pericardium* of the Heart alſo was taken off. But divers perſons ſeeming to doubt of the certainty of the Experiment (by reaſon that ſome Tryals of this matter, made by ſome other hands, failed of ſucceſs) I caus'd at the laſt Meeting the ſame Experiment to be ſhewn in the preſence of this *Noble Company*, and that with the ſame ſucceſs, as it had been made by me at firſt; the Dog being kept alive by the Reciprocal blowing up of his Lungs with *Bellows*, and they ſuffered to ſubſide, for the ſpace of an hour or more, after his *Thorax* had been ſo diſplay'd, and his *Aſpera arteria* cut off juſt below the *Epiglottis*, and bound on upon the noſe of the Bellows.

CHAPTER V

RESUSCITATION

THE importance to life of respiration and the fatal consequences if it ceased for more than a few minutes must have been recognized from the earliest times Even the most primitive and ancient peoples seemed to have known that air blown into the mouth of the apparently dead had powerful restorative properties

A clear description of the resuscitation of a moribund patient by mouth to

FIG 10 VESALIUS EXPERIMENTS WITH ARTIFICIAL RESPIRATION (1555)
This illuminated letter appears at the commencement of the chapter describing the experiments in which an animal was kept alive after the chest was opened by insufflating air into the lungs through a tube inserted into a tracheotomy opening

mouth inflation of his lungs is given in the Bible There is described how Elisha resuscitated the child of the Shunammite woman in the following manner

And he went up, and lay upon the child and put his mouth upon his mouth, and his eyes upon his eyes and his hands upon his hands and he stretched himself upon the child and the flesh of the child waxed warm [1]

In conformity with present day custom the name of Elisha should perhaps be attached to this method of resuscitation In at least two papers [3] the mouth to mouth method of artificial respiration is named after him, though it is used in a modified form An example of the application of the original method is given in the following quotation of 1744 [4]

I applied my mouth close to his and blowed my Breath as strong as I could but having neglected to stop his nostrils all the Air came out at them Wherefore taking

hold of them with one Hand and holding my other on his Breast at the left Pap, I blew again my breath as strong as I could raising his Chest fully with it, and immediately I felt six or seven very quick Beats of the Heart, his Thorax continued to play and the Pulse was felt soon after in the Arteries

To Paracelsus in the sixteenth century belongs the credit of inflating the lungs with a bellows connected to a tube inserted into the mouth of the asphyxiated patient His method was taken up by Vesalius a little later to keep animals alive while demonstrating their anatomy The illustration[6] (Fig 10) taken from the latter's book, *De Corporis Humanis Fabrica*, published in 1555, shows a preliminary tracheotomy being performed

In the words of Vesalius

That life may in a manner of speaking be restored to the animal, an opening must be attempted in the trunk of the trachea, into which a tube of reed or cane should be put, you will then blow into this, so that the lung may rise again and the animal take in air Indeed with a slight breath in the case of this living animal the lung will swell to the full extent of the thoracic cavity, and the heart become strong and exhibit a wondrous variety of motions[6]

In 1667 before the Royal Society, of which he was curator, Robert Hook read a paper[7] entitled

An Account

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This Noble Experiment came not to the Publisher's *hands till all the preceding Particulars were already sent to the Press and almost all Printed off, (for which cause also it could not be mentioned among the* Contents) *And it might have been reserved for the next opportunity had not the considerableness thereof been a motive to hasten its Publication It shall be here annexed in the Ingenious* Author *his own words as he presented it to the* Royal Society Octob 24 1667 *the Experiment it self having been* both *repeated (after a former successful trial of it, made by the same hand a good while agoe)* and *improved the week before, at their* publick Assembly *The Relation it self follows*

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RESUSCITATION

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A clear description of the resuscitation of a moribund patient by mouth to

Fig. 10. Vesalius' experiments with Artificial Respiration (1543)

This illuminated letter appears at the commencement of the chapter describing the experiments in which an animal was kept alive after the chest was opened by insufflating air into the lungs through a tube inserted into a tracheotomy opening.

mouth inflation of his lungs is given in the Bible.[1] There is described how Elisha resuscitated the child of the Shunammite woman in the following manner:

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> I applied my mouth close to his, and blowed my Breath as strong as I could, but having neglected to stop his nostrils, all the Air came out at them. Wherefore taking

society published a handbook on resuscitation which was translated into English by a certain Dr T. Cogan. He and a friend, Dr Hawes, called a meeting of fellow enthusiasts at the London Coffee House on April 18th, 1774. At this meeting a society was formed later to become the Royal Humane Society. The records of the society show that the members soon sought the advice of John Hunter, the surgeon, on methods of restoring life to the drowned. In his reply Hunter quoted the results of experiments he had *carried out on dogs in 1755*[8]. *In these, the thorax of the dog was opened by removing the sternum exposing the thoracic viscera. The dog was kept alive* by artificial respiration carried out by means of a double chambered bellows—his own invention. One chamber of the bellows filled the lungs, the other exhausted them. On the basis of these experiments Hunter advised that similar means be used to resuscitate drowned people.

Hunter's advice received confirmation in an independent report in 1776[9] invited by the Humane Society from Dr William Cullen, Professor of Physic at Edinburgh. Cullen, too, advised inflation of the lungs with bellows, recommending in particular the pattern developed by Dr Alexander Monro the Second, Professor of Anatomy at Edinburgh, and who, like Hunter, used live animal preparations both for teaching and research.

As a result of the formation of the English and Dutch societies, and perhaps stimulated in this country at any rate by Hunter's and Cullen's suggestions, many devices for resuscitation were invented.

To many of the inventors the Humane Society awarded medals or other prizes. The following quotation[10] mentions some of the better known of these:

> Desgranges of Lyons (1786) was the author of a pump which he called the 'pyulque'. Hans Courtois, of Tourney, in 1789 invented a double pump which alternately injected and aspirated air into the lungs through a tracheotomy canula. To avoid the complicating operation of tracheotomy, Fine of Geneva (1800) devised a special intralaryngeal tube made of leather which he inserted through the nose. Pia and Garey used long gum elastic tubes or laryngeal catheters, which were loosely fitted into the nose or into the larynx through the glottis. The experiments of Goodwyn (1788) contributed considerably toward the general adoption on the Continent of an English pump devised by Nooth. The intralaryngeal canula of James Curry (1791) was also well known. It was simpler than Courtois' machine, and could be used either in the nose, larynx or trachea. John Murray modified this appliance so that it would inject warm air. Cap of Lyons (1828) also described an intubating tube attached to a pump. Lecat, Louis, Tissot, Reamur, Fontana, Marc A. Portal in France, Johnson in England, and Troja in Italy were strong advocates of insufflation of the lungs for asphyxia, believing this the best method to restore the victims of asphyxia from no matter what cause. . . . The emergency chests, first aid outfits and the boite de secours which were supplied to police surgeons and life saving stations on the coasts of England, France and the Continent were not considered complete without some form of air pump or apparatus for intra oral, nasal or pharyngeal insufflation.

And becaufe fome Eminent Phyfitians had affirm d, that the *Motion of the Lungs* was neceffary to Life upon the account of promoting the Circulation of the Blood and that it was conceiv d, the Animal would immediately be fuffocated as foon as the Lungs fhould ceafe to be moved, I did (the better to fortifie my own *Hypothefis* of this matter, and to be the better able to judge of feveral others) make the following additional Experiment, *viz*

The Dog having been kept alive, (as I have now mentioned) for above an houre, *in which time the Tryal had been often repeated, in fuffering the Dog to fall into Convulfive* motions by ceafing to blow the Bellows and permitting the Lungs to fubfide and lye ftill, and of fuddenly reviving him again by renewing the blaft, and confequently the motion of the Lungs This, I fay having been done, and the Judicious Spectators fully fatisfied of the reallity of the former Experiment, I caufed another pair of Bellowes to be immediately joyn d to the firft, by a contrivance, I had prepar d, and pricking all the outer coat of the Lungs with the flender point of a very fharp pen knife, this fecond pair of Bellows was mov d very quick whereby the firft pair was alwayes kept full and alwayes blowing into the Lungs, by which means the Lungs alfo were alwayes kept very full and without any motion, there being a continual blaft of Air forc d into the Lungs by the firft pair of Bellows fupplying it as faft, as it could find its way quite through the Coat of the Lungs by the fmall holes pricked in it, as was faid before This being continued for a pretty while the Dog, as I expected lay ftill as before his eyes being all the time very quick, and his Heart beating very regularly But, upon ceafing this blaft and fuffering the Lungs to fall and lye ftill, the Dogg would immediately fall into Dying convulfive fits but be as foon reviv d again by the renewing the fulnefs of his Lungs with the conftant blaft of frefh Air

Towards the latter end of this Experiment a piece of the Lungs was cut quite off, where twas obfervable that the Blood did freely circulate and pafs thorow the Lungs, not only when the Lungs were kept thus conftantly extended but alfo when they were fuffer d to fubfide and lye ftill Which feem to be Arguments, that as the *bare* Motion of the Lungs *without frefh Air* contributes nothing to the life of the Animal he being found to furvive as well, when they were not mov d as when they were, fo it was not the fubfiding or movelefnefs of the Lungs, that was the immediate caufe of Death or the ftopping the Circulation of the Blood through the Lungs but the *want* of a fufficient *fupply of frefh Air*

I fhall fhortly further try whether the fuffering the Blood to circulate through a veffel fo as it may be openly expofed to the frefh Air will not fuffice for the life of an Animal, and make fome other Experiments, which I hope will throughly difcover the *Genuine ufe of Refpiration* and afterwards confider of what benefit this may be to Mankinde

The story of thoracic anaesthesia proper begins during the eighteenth and nineteenth century with the accelerated development of methods of resuscitation

The latter part of the eighteenth century saw the establishment and development in the Low Countries of a society for the resuscitation of the apparently drowned (Maatschappij Tot Redding Van Drenkelingen) This

The Royal Humane Society's Annual Report for 1806 shows the apparatus then advised for resuscitation (Fig 11), the explanatory text to which is taken from the society's report for 1812

The following description of Nooth's ingenious pump (Fig 12) is taken from a book by E Goodwyn[11]

> For this purpose, I propose the instrument ABCDE The brass cylinder AB contains 100 cubic inches of air, and communicates with the atmosphere by the small circular opening 'a The piston DE is of wood, and lined with a soft substance at the bottom E, so as to be airtight The two openings d b, are to allow the air to escape, when the piston is drawn higher than the circular opening 'a The tube C is for the attachment of a smaller one to be inserted into the nose, larynx or trachea
>
> If the lungs are to be inflated the extremity of the small tube must be inserted into one of the aerial passages, and the others properly shut The piston being drawn up and the orifice a closed with the finger, we press down the piston and force the contents of the cylinder into the lungs A few seconds after, we draw up the piston and the air passes from the lungs into the cylinder again Then we remove the finger from the orifice a press down the piston, and the greater part of this expired air escaped into the atmosphere After this, we draw up the piston a second time, while the orifice a continues open, and a volume of fresh air enters into the cylinder which may be forced into the lungs in the same manner

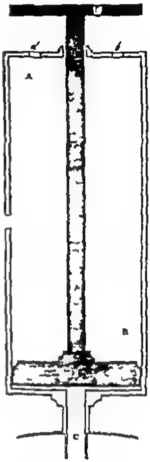

Fig 12

Goodwyn also referred to pumps employing valves which had recently been invented by a Mr Kite of Gravesend, and a Mr Hurlock of St Paul's Churchyard Goodwyn did not approve of these instruments with valves, because 'they must be entrusted often to the ignorant' It is also interesting to see Goodwyn's recommendation regarding oxygen when he states that 'where dephlogisticated air can be procured it should be always preferred to atmospheric air'

James Curry's[12] instruments of 1792, illustrated in Fig 13, were invented before the Royal Humane Society published their own apparatus The illustration shows an endotracheal tube made of silver and an oesophageal tube with a sliding obturator to prevent air being forced into the stomach These two tubes were passed on the same patient in the manner shown in Fig 14 By the time Curry published the second edition of his book in 1815, however, his views had changed ' I believe that neither' (the endo

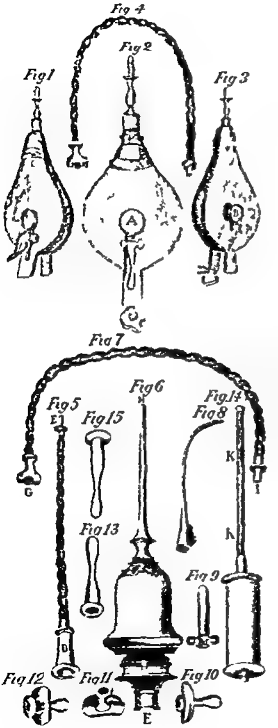

Fig 11 Royal Humane Society's Apparatus (1806)

"Fig 1 2 3 are different views of a pair of bellows for the double purpose of inflating the lungs and injecting warm or stimulating vapour as of rosemary lavender valerian, asafoetida, etc.

The mark A Fig 2 is a lever for filling the bellows with fresh air in inflating B in Fig 3 is a movable circular piece of wood over the clack hole which must be turned over it in inflating and removed aside when the bellows are used as common bellows for injecting stimulating vapours

C, Fig 2 is a brass nozzle which fits into Fig 5 at D for inflating and into Fig 6 at E for injecting stimulating vapours

Fig 4 is a long flexible tube of the same description as Fig 7

Fig 5 is a short flexible tube fitted to the nozzle of the bellows C for inflating its tube F fits into Fig 8 9 10 11 12

Fig 6 is a brass box, inclosed in wood to contain the stimulating substance and is to be connected at E with the nozzle of the bellows Fig 1 and at H with the long pipe Fig 7

Fig 7 a long flexible tube which being fitted at G upon Fig 6 at H is used for injecting vapour or smoke

Fig 8 a curved silver pipe to fit on Fig 5 for inflating the lungs by passing it down the throat beyond the glottis.

Fig 9 a cannula for bronchotomy it fits on Fig 5 at C.

Fig 10 11 12 are nostril pipes of various sizes they fit on Fig 5 F

Fig 13 15 are clyster pipes of different sizes they fit on Fig 7 at I

Fig 14 is a syringe with a flexible tube K K for injecting cordials into the stomach.

tracheal tube nor the oesophageal blocker) 'will be of much use, from the rigidity of the muscles in the greater number of cases of drowning, locking

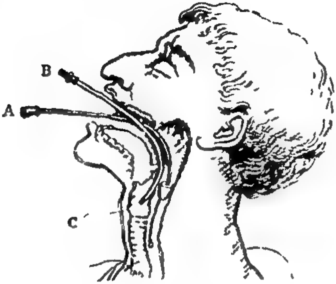

FIG 14

the jaws so close, as to render it impossible to introduce either with certainty' He advocated the routine use of the boxwood nostril tube in drowning, and only made use of the flexible oesophageal tube for the injection of cordials and the removal of laudanum or other poisons from the stomach[13]

Cutting across the now firmly established and accepted beliefs on the efficacy of the bellows in resuscitation came Leroy's dramatic and devastating pronouncements in 1827 In a series of papers[14] to the French Academy of Science he cast grave doubts on the safety of forced inflation of the lungs carried out with bellows

He demonstrated with practical experiments that by blowing forcibly

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FIG 13 CURRY'S RESUSCITATION APPARATUS (1792)

Fig 1 Silver tracheal cannula The cannula is round until within two inches of the end at A when it becomes flat and continues so to the point in order to adapt it to the oblong opening of the windpipe To prevent any injury being done to the sides of the aperture which forms the voice the point of the cannula is closed and rounded off and the openings are made in the sides to allow the air to pass into and out of the lungs

Fig 2 A flexible tube with a brass socket C to fit on the end B of the cannula At the other end is a leather funnel D which can be tied round the nozzle of a common bellows

Fig 3 Wooden nostril tube End A is inserted into nostril B connects to bellows

Fig 4 A brass syringe for injecting stimulating fluids into the stomach via flexible tube (Fig 5) or into rectum via the glyster pipe (Fig 6)

Fig 5 A flexible tube made of spiral wire covered with leather for introducing liquids into stomach A—ivory tip B—ivory sliding piece used to block oesophagus and prevent air entering stomach during inflation C—brass mount

Fig 6 Flexible glyster tube

Fig 7 Brass connecting piece A is attached to cannula Bellows are attached at B

Fig 13

to limit the volume of air inflated With his bellows Leroy claimed that damage to the lungs due to over inflation was unlikely to occur Neverthe

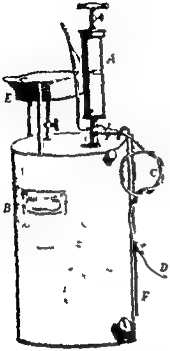

Fig 16 Erichsen's Resuscitation Pump (1845)

A Pump of 20 cubic inches capacity
B 18 gallon gasometer
C Rubber tube connecting pump to patient
D Intubation tube or nostril pipe
E Hot water reservoir or gasometer
F Contents gauge

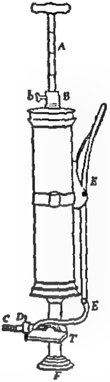

Fig 17 Enlarged Drawing of Erichsen's Pump

A Piston rod with 5 cu in divisions marked on it
B Sliding collar with fixing screw (b) Position of collar on piston rod controls stroke volume of pump
C Rubber tube connecting pump with patient
E Flute key lever controlling the two-way tap (T)
F Inlet to pump from gasometer

less the practice of resuscitation by inflation of the lungs with bellows fell into general disfavour Even the Royal Humane Society did not disregard these opinions and withdrew bellows wherever they had supplied them for resuscitation

For the next fifty years, until Fell and O Dwyer rekindled interest, inflation of the lungs as a method of resuscitation lapsed into desuetude, and during this period reliance was placed on warmth, friction, the 'exhibition' of stimulating vapours and the introduction of cordials into the alimentary canal The idea of inflation however was kept alive by sporadic inventors like Erichsen, whose apparatus (Figs 16 and 17) was described in 1845 [14] In the course of his very lengthy paper Erichsen stated 'in those desperate cases in which submersion has lasted for more than four minutes, or in which there is no

with the lips applied to the resuscitation cannula it was possible to rupture the alveoli causing emphysema and tension pneumothorax, with fatal results

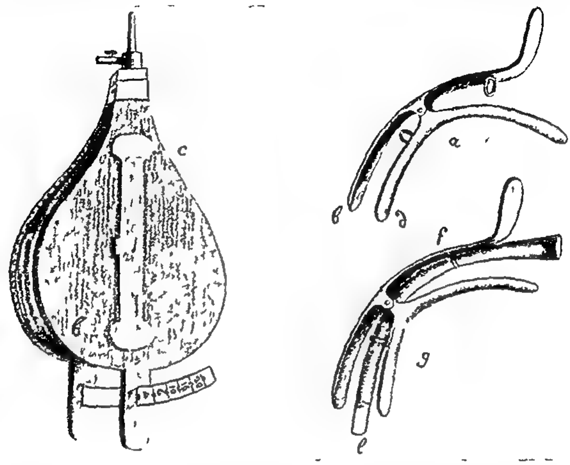

FIG 15 LEROY'S 'SAFETY' BELLOWS AND INSTRUMENTS FOR INTUBATION (1827)

On the left is shown the bellows with a variable stop marked in ages When the stop was placed against the age of the drowned or moribund subject the bellows would deliver a 'safe' volume of air To permit the escape of expired air there was a side tube near the nozzle like Hunter's

On the right is the two-bladed intubating spatula which holds the mouth open depresses the tongue and epiglottis and allows the tracheal tube to be passed via the guiding rings through the larynx into the trachea *(Compare with Fig 169 Crafoord's similar instrument 1938)*

It was his opinion that many patients who otherwise would have recovered were speedily dispatched, by the over enthusiastic use of the bellows in the equipment then issued by the Prefecture of Police (see Appendix, p 151)

These experiments greatly perturbed the Academy, the members of which had been responsible for designing the bellows and recommending that they be issued A committee of investigation was appointed This committee repeated Leroy's animal experiments and confirmed his findings in a report issued in 1829[15] To obviate the worse defect of the bellows then in use Leroy invented 'safety' bellows (Fig 15), which had an adjustment marked in ages

CHAPTER XI

THE BEGINNINGS OF INTUBATION

During all this time while physicians in general were concerned with the problems of resuscitation of the drowned, obstetricians were occupied with those of revival of the newly born For example, Chaussier, an obstetrician of Dijon, wrote a memorandum[1] in 1780 entitled

Sur les moyens propres a determiner la respiration dans les enfans qui naissent sans donner aucun signe de vie, & a retablir cette fonction dans les asphyxies, & sur les effets de l air vital ou dephlogistique employé pour produire ces avantages

This memorandum was presented to the Royal Society of Medicine of Paris, and in it Chaussier condemns the mouth to mouth method because 'it has been known for a long time that expired air in its passage through the lungs acquires a deleterious quality which is harmful to animals which breathe it again The excellent experiments of Priestly and Fontana have demonstrated that the air leaving the chest contains a large quantity of phlogisticated air* and fixed air, neither of which is of any use for respiration, and far from aiding this function, the fixed air which is found in the expiration carries into the lungs a lethal effect '†

Ordinary household bellows had already been in use for resuscitation for some years Chaussier pointed out that they were not without drawbacks for

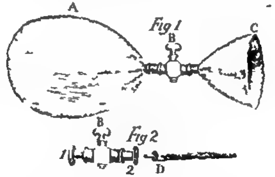

Fig 18 Chaussier's Bag and Mask for Inflation (1780)

'almost always, kitchen and houshold bellows are full of ash and dust, and insufflation carries this *into the mouth* and lungs of the asphyxiated child

* Phlogisticated air = nitrogen
Dephlogisticated air = oxygen
Fixed air = carbon dioxide

† Translation

sign of vitality left and in which, as has already been stated, the measures at present adopted are very generally ineffectual, I would most strenuously recommend the trial of the inflation of the lungs with oxygen gas' He advised that the chest should be inflated with 15 cubic inches of oxygen ten times a minute, the chest and abdomen being compressed after each inflation He stressed the danger of forcible inflation

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Read also Mechanism underlying the various methods of artificial respiration KEITH A *Lancet* 1909 1 747

to a vessel A The connecting tube I consists of soft leather fitted over wire rings as in the modern manner, to maintain its lumen and prevent flattening

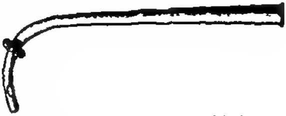

Fig 20 Chaussier's Cannula (1807)

The vessel A has two openings, the top one C connected to the breathing tube and the bottom one B which is left open, and through which the vessel is filled with oxygen The outer container G is filled with water, so that when the patient breathes in and out through the face mask the water flows in and out of the vessel

Later in 1807[2] Chaussier also designed a cannula (Fig 20) for intubation of the larynx to permit more efficient inflation of the lungs This cannula of oval section for easy handling not only had a curvature which approximated to the anatomical shape of the pharynx, but had fixed near the laryngeal end a small sponge which occluded the larynx round the tube Leakage round the tube was minimized, making inflation more effective The latter manoeuvre was carried out by the operator blowing down the broad end of the tube This cannula became the prototype for many of the cannulae which were to follow, although some designed in ignorance of Chaussier's work were almost identical (see Figs 113 and 115)

However efficient Chaussier himself found his instrument, it never became very popular owing to the practical difficulty of intubating the larynx of a new-born child through the mouth by the sense of touch alone This difficulty combined with Leroy's damaging attack in general on the method of insufflating the lungs with bellows, led to the almost total eclipse for the time being of tracheal cannulation as advocated by Chaussier Depaul, however, Chaussier's successor at the Maternite, published in 1845 a comprehensive

Fig 21 Depaul's Cannula (1845)

paper[3] supporting its use Depaul modified Chaussier's tube (Fig 21) by making the laryngeal opening terminal and by altering the curvature

also if the lips and nostrils are not closed tight enough, one blows in vain, the air escapes without entering the bronchi'

In order to overcome these difficulties and objections, Chaussier designed in 1780 a simple apparatus (Fig 18) This consisted of a large reservoir bag A and a face mask C connected by a tap B The reservoir bag was filled with air or oxygen, the face mask applied to the child's face and the bag squeezed rhythmically The appearance of this apparatus and the method of its use bears a striking identity with those of the present day

The lower illustration in Fig 18 shows a tube D which plugged into the outlet inside the face mask, for inflating the lungs through a nostril Both the reservoir bag and the face mask were made of chamois leather, though in the case of the bag a 'well cleaned bladder' or a 'strong varnished taffeta' would serve When the nostril tube was in use the face mask was turned inside out over the tap B The need for airtightness between the face mask and the face was stressed by Chaussier who advised adhesive plaster to make a close joint between the two

Complementary to the bag and mask was an oxygen therapy outfit (Fig 19) which Chaussier described in the same paper To the left is seen the oxygen

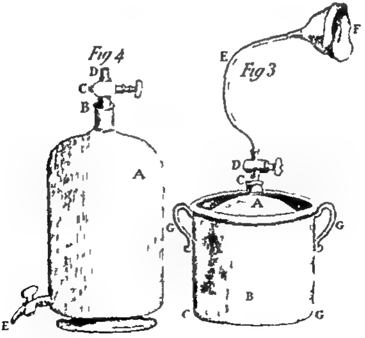

FIG 19 CHAUSSIER'S OXYGEN THERAPY OUTFIT (1780)

storage vessel for the transport of oxygen from the chemist's shop On the right is the inhaler consisting of the face mask F connected by tubing and tap

the nose into the trachea of a patient This led him to treat several cases of oedema of the glottis by successful blind endotracheal intubation

For the relief of respiratory obstruction in diphtheria, Bouchut used a short tracheal tube less than one inch long, having two projections at its upper end resting on the larynx He reported his work in 1858[6] to the French Academy, but his method was condemned outright[7] after a miserable failure at an arranged demonstration before Trousseau, then a medical demigod and a pioneer and advocate of tracheotomy

Fortunately, when O Dwyer, of New York, in 1885[8] (Fig 23) published his report of a successful trial of the same technique as Bouchut, the reception was more kindly So much so, in fact, that a decade after O'Dwyer's report Matas wrote that

> O Dwyer s resurrection of Bouchut s crude ideas on intubation, and his magical transformation of the bloody and tragic picture of tracheotomy in diphtheria into a simple, painless, and bloodless bit of technical jugglery by his perfected method of intubation has practically closed for all time one of the most conspicuous chapters in the history of surgery[9]

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BOUCHUT *Compt Rend Acad Sci* 1858 xlvii 456
BLACHE NELATON and TROUSSEAU *Bull Acad Med Paris* 1858–59 24 99
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Ribemont in 1878 listed many criticisms of these earlier devices in his paper[4] describing his own tube (Fig 22)

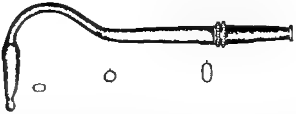

FIG 22 RIBEMONT'S TUBE (1878)

A tube designed for artificial respiration in the newly born child and claimed to be an improvement *on that of Chaussier The shape of this tube was designed after many observations on cadavers* and closely resembled the natural curves The cross section varied in different parts of the tube The tracheal end was cone shaped and was flattened from side to side to pass through the larynx easily and to give a nearly air tight fit The main part of the tube was circular in cross section while near the mouth it was again flattened from side to side for ease in handling with meconium covered fingers

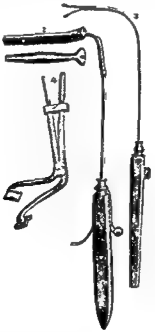

FIG 23 O'DWYER'S TUBE AND INSTRUMENTS (1885) FOR LARYNGEAL INTUBATION IN DIPHTHERITIC CROUP

The tube was designed to lie in the larynx with the expanded upper part resting on the cords

1 Intubation tube showing expanded upper end which rested on cord
2 Tube in place on introducer
3 Introducer showing extensible prong points which gripped inside of tube
4 Mouth gag

Meanwhile, two other attempts at intubation as part of the treatment of asphyxia had been made Desault[5] accidently passed a stomach tube through

Nevertheless, one cannot but wonder whether John Snow would not have forestalled him fifty years before had the surgeons of his day been ready to

FIG 25 THE FELL-O DWYER APPARATUS (c 1888)

This was similar to the original Fell apparatus (Fig 24) but during inflation the operator s thumb was placed over the expiratory orifice O Dwyer s laryngeal tube was a great improvement over the face mask. The laryngeal end was curved at a right angle and fitted with interchangeable conical heads of different sizes designed to fit securely into the larynx preventing the escape of air during inflation Rings were provided for the operator s fingers

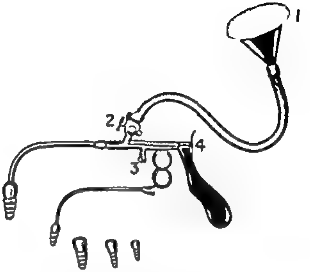

FIG 26 MATAS S MODIFICATION OF THE FELL-O DWYER APPARATUS (1900)[4] (See also fig 140)

The device consists of an O Dwyer pattern tube with a handle and provision for the maintenance of anaesthesia added The anaesthetic was dripped on to the cone (1) The vapour passed via tap (2) into the laryngeal tube The tap was closed during inflation and the latter would be interrupted whilst the patient inhaled air and anaesthetic vapour from the cone

1 Anaesthetic cone (Trendelenburg pattern)
2 Tap
3 Connection for supply of compressed air
4 Expiratory orifice—closed by thumb during inflation

open the chest Snow[5] used the very principles which Matas describes

A young rabbit rather more than half grown, was made insensible by breathing air charged with four per cent of vapour of chloroform in a large jar The trachea was then opened, and a tube was introduced and tied The lungs and heart were then exposed, by making an incision and removing the lower half of the sternum with the adjoining part of the cartilages of the ribs on each side The front of the pericardium was also cut away to expose the heart Whilst these operations were performed, artificial respiration was kept up by means of a bladder of air attached to the tube in the trachea The heart contracted vigorously and quickly, and the lungs were of a light red colour

Other surgeons also experimenting in this new field of surgery, began to try rhythmic inflation of the lungs combined with anaesthesia Tuffier and Hallion[6,7] reported to the Societe de Biologie in 1896 on 'Intrathoracic operations with artificial respiration by insufflation' and 'On the regulation

CHAPTER VII

EARLY CHEST ANAESTHESIA

AFTER an unsuccessful attempt by the then standard Sylvester and Marshall Hall methods of artificial respiration to maintain life in a case of morphine poisoning, Dr George Fell, of Buffalo, applied in the human being the laboratory technique familiar to him of artificial respiration with bellows In 1887[1] he described an apparatus (Fig 24) he had successfully used to maintain artificial respiration, either via a tracheotomy tube or a face mask O'Dwyer, with his experience of intubation in diphtheria (see p 158), soon modified[2] Fell's apparatus, obviating both the possibility of a poor airway when a mask was used, and the need for the operation of tracheotomy before resuscitation could be started A tracheal tube was substituted for the tracheotomy tube or face mask (Fig 25), the bellows were operated by foot and the cornet valve replaced by a simple expiratory hole closed by the thumb This apparatus became known as the Fell O'Dwyer apparatus

FIG 24 THE ORIGINAL FELL APPARATUS FOR ARTIFICIAL RESPIRATION

A bellows (1) delivers a constant stream of air The cornet valve (2) directs the air into the patient's lungs during the inspiratory and into the atmosphere during the expiratory phase

Matas saw that the Fell-O'Dwyer apparatus could revolutionize chest surgery, and successfully adapted it for anaesthesia (Fig 26) He reported in 1899 the first successful use of this apparatus for a thoracotomy during which a tumour of the chest wall was removed The far sightedness of Matas is shown in the following extract from one of his papers[3, 4] in which he advocates the methods in use to day, but which were to receive little encouragement for some forty years

We have now come to a time when new expedients are being devised for preventing pulmonary collapse and for maintaining the functional activity of the lung after opening the pleura *It is these new expedients which promise most hopefully to revolutionize the surgery of the thorax in a manner that will relegate adhesions to a secondary* and humbler plane

The procedure that promises the most benefit in preventing pulmonary collapse in operations on the chest is the artificial inflation of the lung and the rhythmical maintenance of artificial respiration by a tube in the glottis directly connected with a bellows Like other discoveries it is not only elementary in its simplicity but the fundamental ideas involved in this important suggestion have been lying idle before the eyes of the profession for years[5] It is curious that surgeons should have failed to apply for so long a time the suggestions of the physiological laboratory, where the bellows and tracheal tubes have been in constant use from the days of Magendie to the present in practising artificial respiration in animals

others the blow off tube was used to control the degree of residual distension of the lungs at the end of expiration

In 1896, simultaneously with Tuffier and Hallion's paper, Quenu and Longuet described[10] their unsuccessful attempts to prevent the pneumothorax syndrome by deliberately provoking the formation of adhesions by irritating the pleura some little time before the operation In common with many of the surgeons of their day they believed that the cause of the pneumothorax syndrome was the collapse of the lung and that the condition would not occur if the lung was prevented from collapsing It was natural, therefore, that their next approach to the problem was to prevent the collapse of the lung by increasing the intrabronchial pressure,' forcing 'the lung against the window in the thoracic wall throughout the operation ' This was achieved by 'making the animal breathe into a container of compressed air which encloses the upper part of the body, an apparatus very similar to that used by divers ' Soda lime and a chloroform soaked sponge were placed inside the container and a mercury manometer used to observe the degree of positive pressure When 5–6 cm of mercury (a rather high pressure as it now appears to us) were reached, 'A large window is opened in the chest wall and the ribs retracted to one side The lung tends to herniate through the opening and appears to the surgeon, convex, smooth, pink and breathing '

Unlike Quenu and Longuet, Tuffier and Hallion thought that this state of affairs was unsatisfactory,[7] pointing out that 'in most intrathoracic operations it is an advantage to have light and space in the pleural cavity This means, then, that the lung far from filling all the cavity occupies the smallest volume possible compatible with efficient circulation '

Tuffier and Hallion clearly anticipated present day methods by using rhythmic inflation The incorporation and use of a water valve for varying the expiratory pressure was later to be adopted by Tiegel Tiegel, however, did not follow Tuffier and Hallion's good practice of assisting the respiration Had he done so he might not have encountered the problem of carbon dioxide retention, which was to prove such a stumbling block in the positive pressure and insufflation methods during the next thirty years

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of intrabronchial pressure and anaesthesia in artificial respiration by insufflation,' in which they stated that

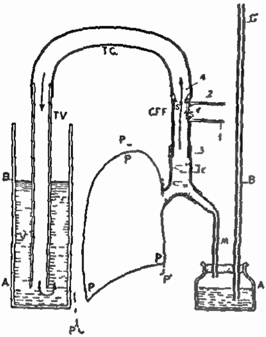


FIG 27 TUFFIER AND HALLION'S METHOD (1896)

> one of us has been able to apply successfully in man, a technique for partial resection of the lung, with which he had previously experimented in animals

They felt that for satisfactory operating conditions

> expiration should continue unencumbered, despite the wide opening of the pleura, even when this is completely free from adhesions Artificial respiration by insufflation alone, would appear capable of meeting these requirements

A diagrammatic representation[8] of the method Tuffier used for maintaining life during open chest surgery is shown in Fig 27 Rhythmic inflation of the lungs was carried out but expiration occurred against a resistance, the back pressure of which could be varied The main part of the apparatus consisted of the François Franck cannula (CFF) connected to the respiratory tract (tr) To another limb of the cannula (1) is connected a bellows while to the third is connected a tube (TC) leading to the water valve Inside the cannula is a flap valve (2) having two airtight seatings, one vertical and one horizontal (S S) When air is forced from the bellows along the horizontal pipe (1), the flap valve is forced into the horizontal position and the air passes via the pipe (3) into the lungs At the end of the inflation stroke of the bellows the valve falls away from its horizontal seating and allows the expired air from the lungs to pass out *along the tube (T C) through the water valve (T V) into the outside* atmosphere A very similar valve for use with the Oxford Vaporizer was described by Neff in 1945[9] The degree of resistance to expiration, and with it the degree of distension of the lungs, is controlled by the depth to which the tube is submersed in the water The manometer was added to the diagram to indicate the fluctuations of pressure (B G) within the lungs

The Tuffier and Hallion method of anaesthesia with this apparatus foreshadows to a striking extent present day methods A perfect airway was maintained by intubation of the trachea with a long copper tube When the lungs had been inflated to the desired degree with the bellows, expiration was allowed to take place through the blow off tube In some cases the blow-off tube was not used and expirations passed freely into the outer air In

opening the chest, important circulatory changes occurred in the collapsed lung He claimed that distension of the alveoli in the normal lung tended to

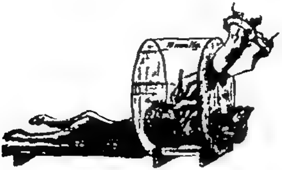


Fig 28 Sauerbruch's experimental Negative Pressure Box used in open chest operations on dogs The dog's chest is enclosed in the box in which the pressure is —10 mm Hg (1904)

restrict the circulation through the lung The collapsed lung, on the other hand, became hyperaemic and the circulation through it might be even greater than through the opposite side Thus a considerable shunt of blood through a non aereating lung occurred with a consequent reduction in the oxygen carriage, and an increase of carbon dioxide in the blood It was this, he believed, that caused the cyanosis and dyspnoea of the pneumothorax syndrome

It was natural, therefore, for him, in searching to remedy this condition, to concentrate on restoring the distended condition of the lung by producing

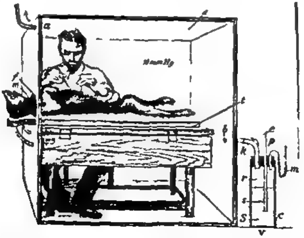


Fig 29 Negative Pressure Operating Chamber for use in experimental open chest operations on dogs (Sauerbruch 1904)

a differential pressure within and without the lung Like most of his colleagues he thought that spontaneous respiration on the part of the patient

CHAPTER VIII

THE POSITIVE PRESSURE PERIOD

LEROY's adverse report in 1827 (see p 35) to the French Academy of Science, in which he condemned the use of bellows as being dangerous, led to the decline in popularity and the virtual disappearance of this method of artificial respiration, and with it the art of intubation of the trachea Little wonder, then, that the technique of intubation and the design of tubes for this purpose advanced little during the nineteenth century Thus it came about that when thoracic surgery was taking its first halting steps, the art of blind tactile intubation through the mouth had been almost completely lost So much so, that when O'Dwyer commenced his researches on intubation for croup in 1880, he was, on his own admission, unaware that this had already been attempted some thirty years before

The technique of artificial respiration by intubation and inflation with bellows was widely used for experimental animals in the laboratory This rather traumatic procedure, and the somewhat crude instruments then available for it, occurred to surgeons as possibly adaptable for use in human beings, but the difficulties of inserting the tube into the human larynx were apparently sufficiently great to damp any but those with the most tenacious initiative The frequently expressed opinion of authorities of the stature of Willy Meyer[1] in papers of this period was that intubation as a routine clinical method was not a practical procedure Even nearer to the present day more than one Continental surgeon regarded intubation as a manoeuvre needing more than average skill As late as 1938 an introducer for endotracheal tubes similar to that of Leroy was invented, because the author thought that direct laryngoscopy and intubation required exceptional skill (see Fig 169, p 134)

The difficulties of intubation stimulated a search for methods other than those used for laboratory animals of defeating the problem of pneumothorax in chest surgery

In Germany, Sauerbruch, then a young assistant, was charged, in 1893, by his chief, Professor von Mickulicz, to investigate further the pneumothorax syndrome and not only to discover why the harmful effects occurred, but if possible to evolve a means of defeating them

Sauerbruch published[2] after a considerable amount of experimental work (Figs 28 and 29), a paper which though repeating many of Quenu and Longuet's suggestions of 1896 introduced a new era of understanding and research into the problems of anaesthesia for open chest surgery Sauerbruch believed that when the intrapleural negative pressure was destroyed by

inside the chamber was kept at 10 mm Hg below that of the atmosphere The patient continued to breathe spontaneously

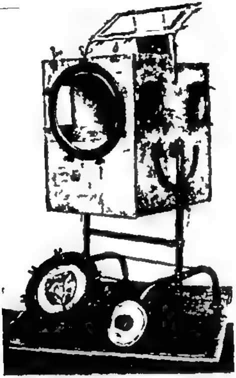


FIG 32 THE ORIGINAL BRAUER APPARATUS FOR POSITIVE PRESSURE ANAESTHESIA IN OPEN CHEST SURGERY (1904)

Compressed air was fed into the box which enclosed the patient's head and the anaesthetist's arms Anaesthesia was maintained by oxygen and chloroform from a Roth Drager apparatus in a manner similar to that shown in Fig 33

When anaesthetized the patient's head was thrust through the large air tight collar and then placed in the chamber through the large aperture The collar was bolted in place The anaesthetist passed his hands into the chamber via the two holes at the side which were rendered air tight by cuffs The patient was observed through the top window

In spite of the widely open thorax the exposed lung did not collapse as it would do in the ordinary way There were, of course, the practical difficulties of operating in such a closed chamber, but these were minimized when it appeared then that the pneumothorax problem had been solved

Sauerbruch was no doubt aware of the Spirophore (Fig 31) which had been invented by Woillez in 1876,[4] and perhaps even of its precursor described by Lewins in 1840 [5]* The negative pressure chamber of Sauerbruch may well have been a development of the Spirophore adapted for thoracic operations

* Dr Lewins of Leith described an apparatus for artificial respiration in which the body with the exception of the head be *in vacuo* or nearly so This is easily done by putting the body to be operated upon in a box that can be made air tight On the top a large syringe is placed which communicates with the interior

By elevating the piston of the syringe a partial void is created to fill up which the air of the atmosphere rushes into the lungs through the trachea and distends the chest Expiration is accomplished by depressing the piston

was essential To accomplish all this Sauerbruch devised the 'negative pressure' method The operating room (Fig 30) consisted of an airtight

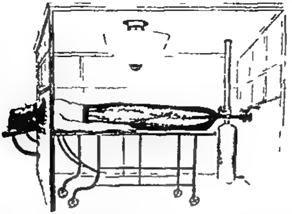


Fig 30 Negative Pressure Operating Chamber Patient's legs and abdomen were enclosed by a cuff connected to outside atmosphere (Sauerbruch 1904)

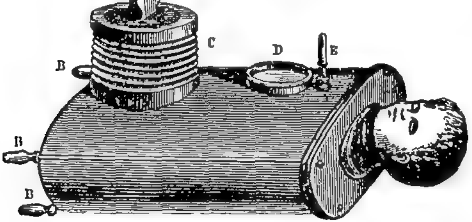


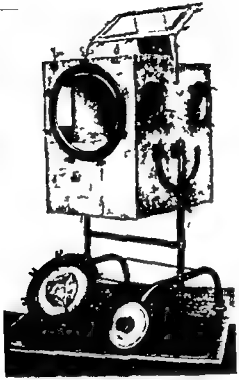
Fig 31 Woillez's Spirophore (1876)

The apparatus consists of a cylinder of zinc or galvanized iron big enough to receive the body of an adult up to the neck It is furnished with small wheels which allow it to be dragged quickly to the place where it is needed This cylinder placed almost horizontally and a little inclined is hermetically closed below and open above Through this upper opening the body of the patient is slid with the help of a sort of stretcher furnished with rollers on to which it is placed first of all Then the upper opening is closed round the neck with the help of a diaphragm which is fixed to the edges of the opening The head thus left free rests on an appropriate support An airtight and floating material hanging from the obturator diaphragm is fixed around the neck or head (from the chin to the occiput) to avoid as much as possible the passage of the exterior air into the interior of the apparatus when it is being emptied The air thus confined inside the apparatus around the body of the patient can be rapidly partially withdrawn by the aid of a strong aspirating bellows with a capacity of about 20 litres placed outside the principal container

The movement of the chest was observed through the window D or by watching the rise and fall of the rod E which rests on the patient's sternum

chamber which contained the whole team as well as the patient with the exception of his head which projected outside the chamber The pressure

inside the chamber was kept at 10 mm Hg below that of the atmosphere The patient continued to breathe spontaneously



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By elevating the piston of the syringe a partial void is created to fill up which the air of the atmosphere rushes into the lungs through the trachea and distends the chest Expiration is accomplished by depressing the piston

The publication in 1904 of Sauerbruch's painstaking researches monopolized the attention of the profession, and such a deep impression was made

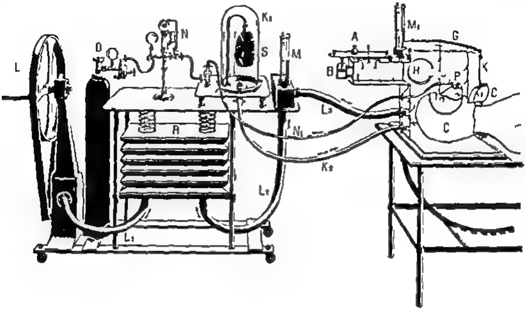


FIG 33 BRAUER'S SECOND APPARATUS PRODUCED IN CONJUNCTION WITH THE DRÄGER COMPANY (1905)

The compressor L supplied air under pressure to the spring loaded bellows R the pressure within which is kept uniform by the springs The air passes via the tubing L_2 and L_3 to the box in which the head is contained The degree of pressure is indicated on the manometer M and controlled by the sliding weight A B is a damper which prevents chattering of the escape valve

The anaesthetic circuit is quite separate Oxygen from the cylinder O is led into the Dräger drip vaporizer N and then via N_1 to the face mask The reservoir bag S is contained in a bell jar which is in communication with the head container and is thus subject to the same amount of positive pressure

that the stimulus to develop methods which utilized principles other than those of differential pressure with spontaneous breathing was removed for the next twenty years

A medical colleague of Sauerbruch, Brauer, who for a short time also *worked at Marburg, independently and at the same time as Sauerbruch* carried out animal experiments with the same end in view Instead of enclosing the subject in a negative pressure chamber, Brauer preferred to increase the intrapulmonary pressure, by placing the head of his subject in a positive pressure chamber His results were published simultaneously[6] and in the same issue of the journal as Sauerbruch's

There was apparently little difference, if any, to be noticed clinically between the two systems In fact, Brauer pointed out that so long as there was a difference of, say, 10 mm Hg between the extrapulmonary and intrapulmonary pressures, it did not matter greatly whether the latter was 760 or 770 mm Hg

Of necessity the negative pressure method involved bulky and expensive

apparatus which could not easily be transported (Figs 30 and 36) In the positive pressure method, only the patient s head needed to be enclosed in the

Fig 34 Murphy s Positive Pressure Apparatus (1905)[9]

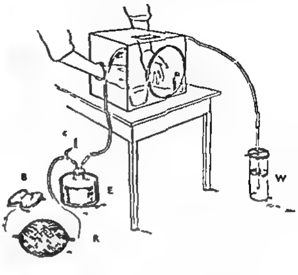


Fig 35 Diagram of Murphy s Apparatus

A simple apparatus of Brauer pattern consisting of a double valve foot pump (B) for maintaining pressure a rubber reservoir bag (R) and a jacketed ether bottle (E) The air may be diverted over the ether or not by manipulation of clip (c) Inlet and outlet air pipes are of ½ inch diameter which can be opened if positive pressure is not needed (W) = water valve for control of pressure

apparatus Within a short time, other forms of positive pressure apparatus were devised which were both portable and cheap

Brauer s original apparatus (Fig 32) consisted of a large box into which the patient s head was placed after anaesthesia had been induced Anaesthesia was maintained by oxygen and chloroform from a Roth Dräger apparatus Before opening the chest the pressure inside the box was raised, by feeding compressed air into it The following comment on Brauer's method is illuminating

Some observers who have seen Professor Brauer s head chamber clinically applied in surgery of the human state that cyanosis and dyspnea have been conspicuous factors In such instances one or two avoidable conditions are present If unnecessary high pressure is employed under compression* of the pulmonary capillaries ensues the right heart may become engorged and a rise in pulmonary pressure occurs This should not occur however except in the hands of unskilled operators The more frequent cause of dyspnea in these cases is incomplete ventilation of the lung alveoli due sometimes to the insufficient supply of oxygen but more often to the stagnation of carbon dioxid, the escape of which is not adequately provided for either in the construction of the apparatus or in its manipulation [7]

* Presumably over-compression was intended by the author

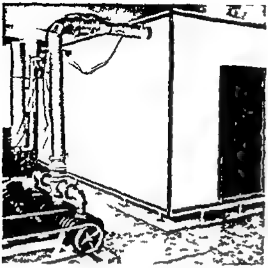


Fig 36

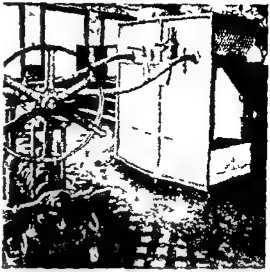


Fig 37

Fig 36 Willy Meyer's combined Positive and Negative Pressure Apparatus (1909)[10] The operating chamber inside which the pressure was kept below atmospheric

Fig 37 Within the Negative Pressure Chamber of Fig 36 was another chamber kept at positive pressure and into which projected the head of the patient There was also accommodation for the anaesthetist and his equipment

Brauer devised[8] a second machine (Fig 33) with the help of the Dräger company The size of the box was reduced and as in the previous machine, the Dräger anaesthetic apparatus used A cylinder supplied oxygen to which was added ether or chloroform A reservoir bag and breathing tube leading to a face mask completed the apparatus Into the box a flow of 30–60 litres per minute of compressed air was maintained to ensure that expired air was removed from the head chamber It should be noted that the reservoir bag of the anaesthetic machine is enclosed in a glass chamber connected to and, therefore, at the same pressure as the head chamber Brauer preferred to use a large hinged flap valve and a weight to control the degree of positive pressure, having found that water valves and rubber balloons (see Fig 42) developed harmonic frequencies which caused the pressure to fluctuate greatly

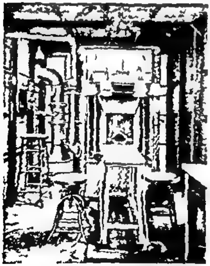


Fig 38 View of the interior of Meyer Negative Pressure Operating Chamber showing the operating table and stools for the surgeons Standing inside the operating chamber is the positive pressure chamber for the patient's head and the anaesthetist

The differential pressure principle of Brauer's and Sauerbruch's machines was very quickly taken up by surgeons not only throughout Germany but

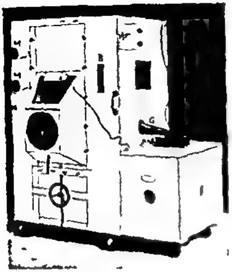


FIG 39

FIG 40

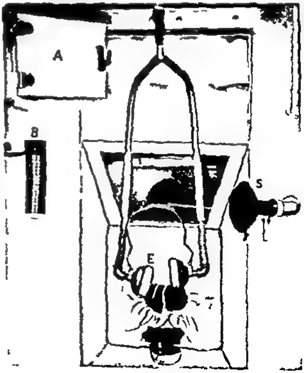
FIG 39 ROBINSON'S IMPROVED POSITIVE PRESSURE APPARATUS (1910)[11]

The apparatus consisted of two parts a sheet metal cabinet 5½ × 3½ × 4 feet which contained the anaesthetist and the patient's head and a wooden box 2½ × 2 × 3 feet which contained two ventilating pumps and two ¼ h p motors

The front of the cabinet and the pump box shows the orifice with a rubber collar for the patient's head Above it is a window and light so that the patient's face can be observed by the surgeon (M M) are speaking tube openings to allow communication between surgeon and anaesthetist (B) Window behind which is a manometer indicating pressure within the cabinet (G) Heavy rubber glove permitting control of pumps by anaesthetist

FIG 40 Anaesthetist seated in Robinson's Cabinet with right hand on regulator of air escape valve and earpieces in position Rubber glove lying on pump controls

FIG 41 Front of Robinson's Cabinet from interior showing A—inner door of air lock via which anaesthetist is supplied B—barometer E—earpieces enabling anaesthetist to hear surgeon's remarks S—speaking tube connected to megaphone M



elsewhere (Fig 34) The positive pressure method was most favoured because the apparatus was comparatively simple

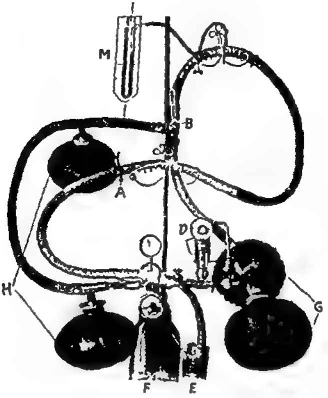


FIG 42 KUHN'S POSITIVE PRESSURE APPARATUS (1905)

A Connection for endotracheal tube
B Three way tap
D Drager chloroform vaporizer
E Water valve
F Oxygen cylinder
G Balloons for oxygen and chloroform
H Balloons for oxygen only
M Manometer

By 1910 the basic principles of the differential pressure cabinet type apparatus had reached its zenith of complexity in the form of Meyer's and Robinson's cabinets (Fig 36 and 39) By the time, however, they were invented and being used, the equally effective and more simple positive pressure machines of Tiegel had been developed and taken up everywhere

Kuhn of Kassel was one of the few who persisted in the use of endotracheal tubes passed blindly through the mouth and he became very expert in their passage, as well as an ardent exponent and propagandist for their use He was responsible for the invention of two positive pressure machines for use with endotracheal tubes His first machine (Fig 42)[12] is interesting in that two positive pressure circuits are used one for oxygen and chloroform and one for oxygen alone Oxygen was admitted from the cylinder F either via

the Drager chloroform drip apparatus D into the two chloroform reservoir bags G, or direct into the two oxygen bags H as required The tap B connected the patient either with the oxygen bags or the chloroform and oxygen bags so that the depth of anaesthesia could at once be lightened should dangerous symptoms be manifest

The mixture then passed down the pressure tubing to the endotracheal

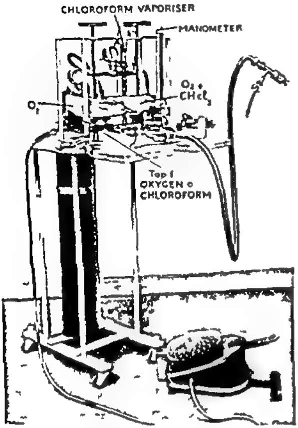


Fig 43

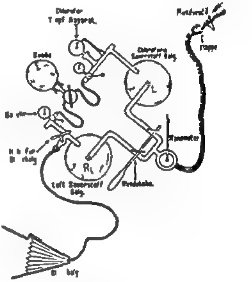


Fig 44

Fig 43 Kuhn's Revised Positive Pressure Apparatus (1906)
Fig 44 Diagram of Kuhn's Positive Pressure Apparatus (1906)

tube connection at A All surplus gas and expired gases passed out into the atmosphere via the water valve E, which also served to control the degree of positive pressure This apparatus was modified, and its final form is shown in Fig 43 and 44 [13] Like the previous one it is divided into two circuits, one for oxygen and air and the other for chloroform The oxygen from the cylinder (B) is diverted by a tap to one or both of the concertina bags (L R) In passing to the container (L) the oxygen picks up chloroform from the vaporizer In passing to the other bag (R) air may be added from the foot bellows The pressure in the concertina bags (R and L) is maintained by weights on them, excessive pressure being prevented by automatic blow off valves The tubes leading from the bags to the breathing tube are provided with linked taps so that the mixture of oxygen and chloroform can be varied at will The degree of positive pressure is controlled by a mechanical expiratory valve

Kuhn also evolved in 1906, at the same time,[13] a 'circle' closed circuit

elsewhere (Fig 34) The positive pressure method was most favoured because the apparatus was comparatively simple

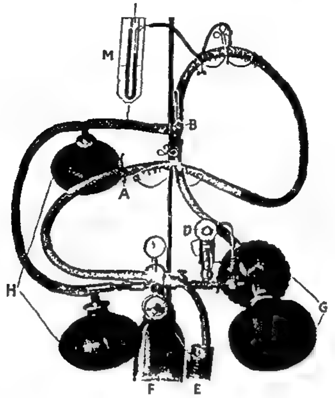


FIG 42 KUHN'S POSITIVE PRESSURE APPARATUS (1905)

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absorption apparatus (Fig 45 and 46), for use with chloroform It is little wonder in view of the obviously excessive dead space and the probably high

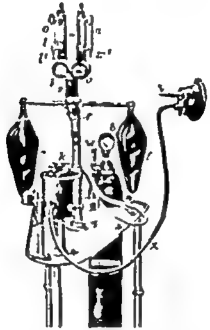


Fig 47 Brat and Schmieden's Apparatus 1908

This apparatus was designed for constant positive pressure or for rhythmic inflation of the lungs Oxygen from the cylinder passed either through the liquid anaesthetic vaporizers (l and m) into the bag (f) or directly into the other bag (g) The main conduit (h) has two taps one (k) permitted normal respiration or positive pressure the other tap (i) situated next to (k) had three positions which allowed either inflation of the lungs with oxygen and pressure expiration at atmospheric pressure or expiration assisted by negative pressure developed by diverting the oxygen into an injector mechanism (x)

resistance of the small bore breathing tube that this apparatus did not progress beyond the experimental stage

In 1908 appeared one more of the by now numerous reviews[14] of chest anaesthesia The authors, Brat and Schmieden, came to the conclusion that artificial respiration by inflating the lungs when the chest was open would be more efficient if the patient's own respiration could be abolished They suggested that this abolition could be accomplished either by the injection of curare which would paralyse the respiratory musculature (a suggestion never put into practice), or by the production of deep anaesthesia They also observed and noted that if the patient's lungs were inflated with an excess of oxygen, apnoea was likely to occur Artificial respiration then became easy

Brat and Schmieden therefore anticipated present-day techniques of controlled respiration In practice, however, they used the positive pressure method They were unwilling to use curare, a drug with a lethal reputation, while deep anaesthesia with chloroform had its own hazards They reserved the inflation device built into their machine (Fig 47) for emergencies only

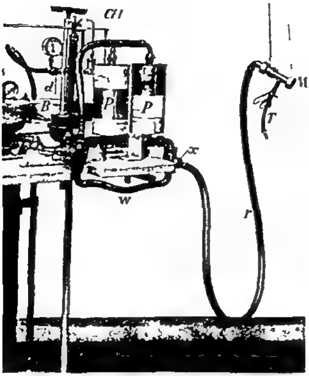


FIG 45 KUHN'S POSITIVE PRESSURE CLOSED CIRCUIT APPARATUS *(1906)*

Oxygen from a cylinder picks up chloroform in the vaporizer (Chl) and passes into a bellows (B) A positive pressure variable at will between 5 and 15 cm H O is produced by varying the tension of a spring acting on the bellows The gases then pass via a non return valve to the breathing tube (r) thence to the endotracheal tube (T) The expired air returns along the single breathing tube through the shunt tube (W) to the canisters containing caustic soda (P P) After passing through these the gases return to the bellows and the inspiratory side

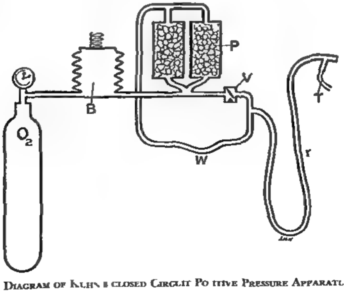


FIG 46 DIAGRAM OF KUHN'S CLOSED CIRCUIT POSITIVE PRESSURE APPARATUS (1906)

emergency chest operations, adapted Brauer's positive pressure principles, and in 1908 improvised a machine (Fig 48)[16] which proved so trouble-free and effective that he recommended it for all chest cases It was simple, cheap and portable In this apparatus oxygen from the cylinder was led into the reservoir bag (B) which also served as a vaporizer for the ether, and thence to the face mask The surplus mixture escaped via the water valve (W), raising or lowering the tube of which varied the degree of resistance to expiration and with it the degree of distension of the lungs The depth of anaesthesia was regulated by injecting ether into the reservoir bag via the tap (H) with a syringe

The next year, 1909, Tiegel[17] improved his apparatus (Fig 50) adding two drip vaporizers for chloroform and ether He also invented, and incorporated with his apparatus, a special bag for the disposal of vomit (Fig 49) without interrupting the positive pressure anaesthesia The bag was slid into place to collect the vomit and was returned to the position illustrated when the vomiting had ceased The literature of this period, and indeed for the next twenty years, is characterized by the interest and concern paid to the problem of vomiting during anaesthesia, and by the striking absence of mention of the part played by secretions either in increasing the difficulties of anaesthesia or in spreading disease from one part of the lung to another

The design of Tiegel's positive pressure apparatus was eventually adopted by Sauerbruch in spite of the latter's original advocacy of the negative

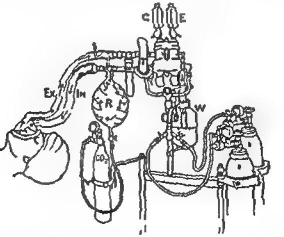


FIG 51 THE TIEGEL HENLE POSITIVE PRESSURE APPARATUS USED IN SAUERBRUCH'S CLINIC IN 1937

This more modern apparatus is divided into two separate circuits—as was the older pattern Oxygen from the cylinder (O) passes either direct into the inspiratory circuit via tap (T) or first picks up chloroform and/or ether vapour from the drip vaporizers (C and E) The gases then pass into the *reservoir bag* (R) and to the patient along the inspiratory tube (In) The expired gases pass from the mask into the expiratory tube (Ex) and reach the atmosphere through the water valve (W) which controls the degree of positive pressure

pressure method, and it is interesting to see that the anaesthetic apparatus illustrated (Fig 51) and advocated in the 1937 edition of Sauerbruch and

The important suggestions and observations of Brat and Schmieden had also been made by two American surgeons, Green and Janeway, in 1909,[15]

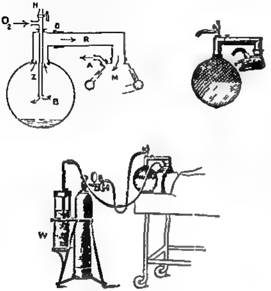


FIG 48 TIEGEL'S FIRST APPARATUS (1908)

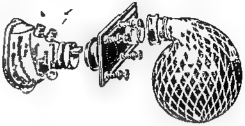


FIG 49 TIEGEL'S VOMIT CATCHER (1909)

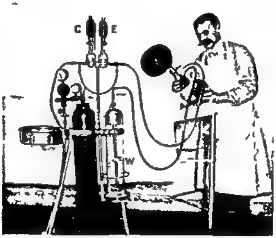


FIG 50 TIEGEL'S SECOND APPARATUS (1909)

In this apparatus drip vaporizers for chloroform (C) and ether (E) were added Oxygen or compressed air was used as a source of pressure Normally oxygen was only added if the patient was not very fit

Fresh mixture is led into mask by one tube and expired gases leave via the other to pass through the water valve (W) before reaching the atmosphere

who, putting these ideas into practice, designed and actually used an apparatus for rhythmically inflating the patient's lungs The apparatus, the first of this type, was intended to perform and maintain what is now called 'controlled respiration' (see Fig 68 and p 80)

Working with Henle at Dortmund, Tiegel, needing an apparatus for

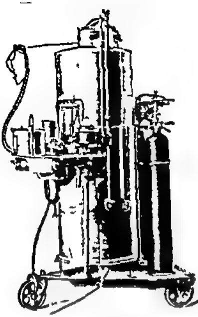


Fig 54

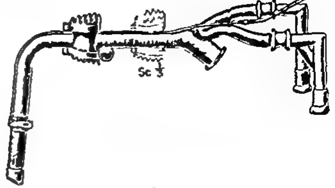


Fig 55

Fig 54 General view of Morriston Davies Positive Pressure Anaesthetic Machine (1911)

This was an elaborate air and chloroform apparatus designed as an improvement on the Brauer Tiegel Henle and Lotsch machines

Fig 55 Morriston Davies endotracheal tube and junction with the inspiratory and expiratory sides of the apparatus Note the bite block the position of which is adjustable the inflatable cuff fitted at the end of the tracheal tube and the fine tube through which the cuff was inflated

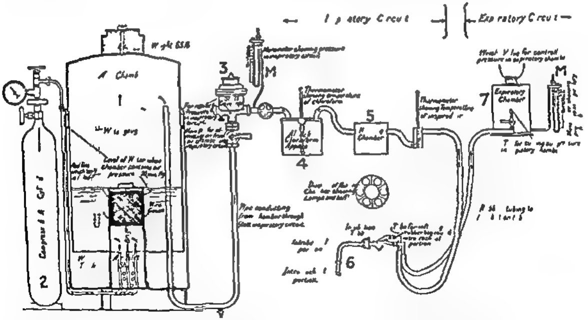


Fig 56 Diagram of Morriston Davies Positive Pressure Apparatus (1911)

The apparatus consists of a gas chamber (1) fed with compressed air and oxygen from the cylinders (2) The pressure within this chamber is regulated by weights placed upon it and is made higher than required within the chest On leaving the chamber the air passes through the adjustable pressure control valve (3) which maintains a steady pressure It then passes through the Alcock's chloroform vaporizer (4) then through the electrically heated chamber (5) and so into the trachea via the endotracheal tube (6) The expired air passes via the exit pipe attached to the endotracheal tube and leaves the circuit through the expiratory chamber (7) which contains a weighted valve M—manometers which register the pressure in the inspiratory and expiratory circuits

O'Shaughnessy's book[18] on chest surgery differs only in detail from that described by Tiegel in 1909

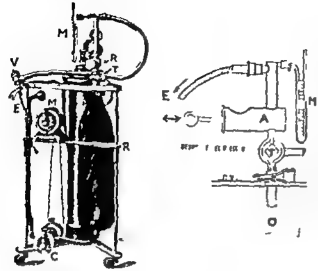
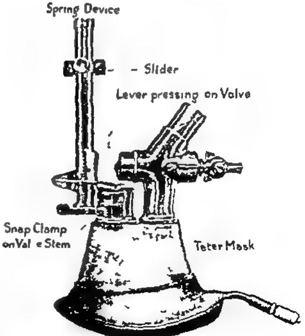


FIG 52 THE LOTSCH POSITIVE PRESSURE APPARATUS (1910)

An apparatus for positive pressure anaesthesia designed by Lotsch which consists of A compressor (C) driven by an electric motor (M) supplies air to the 30-litre reservoir bag (R). The air passes from the bag through the control tap (T) and the anaesthetic vaporizer (V) along the flexible metal tube to the endotracheal tube (F). The expired gas escapes through the spring loaded expiratory valve (V). The degree of positive pressure is controlled by the spring tension of this valve and is indicated by the manometer (M). Oxygen can be given instead of air if necessary by turning tap (T). This automatically switches off the electric motor (M). Anaesthetic was added as required by pulling out the vaporizer slide (A) dripping the ether on to the absorbent gauze within it and then returning the slide

FIG 53 BUNNELL'S SPRING LOADED EXPIRATORY VALVE (1912)

A device for controlling the pressure during nitrous oxide and oxygen anaesthesia administered by the positive pressure method for chest surgery. The device clipped on to the expiratory valve of a Teter anaesthetic mask. A spring bears on to a lever which presses on the valve stem. The spring tension is controlled by a slider which compresses the spring to the desired extent. The more the spring is compressed the greater the pressure on the expiratory valve and the greater the positive pressure in the patient's thorax



Many variations on the positive pressure theme were produced, ranging from Lotsch's simple machine[19] (Fig 52) and Bunnell's valve (Fig 53),[20] to Morriston Davies' elaborate variation (Fig 54, 55 and 56) [21]

A very important conclusion can be drawn from these experiences It is necessary in the course of thoracic operations of long duration to interrupt now and then the

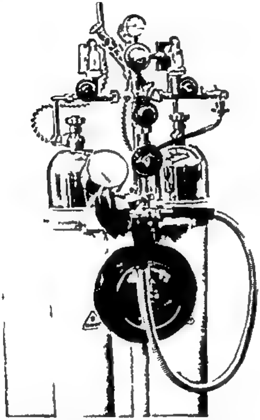


FIG 57 DRÄGER POSITIVE PRESSURE APPARATUS (1918)

Features of this apparatus are an adjustable expiratory valve a spring loaded plate bearing on the breathing bag an injector device which allows air to be mixed with the gases in known proportions for the sake of economy and drip vaporizers for ether and chloroform

pressure, allowing the lungs to collapse, in other words, to interpose at regular intervals brief periods of artificial respiration by means of the apparatus, in order to clear the system of its CO_2 accumulation

In the same paper Meyer describes another case in which thoracotomy was performed Rhythmic pressure was applied for several minutes at a time every quarter of an hour By this means the anaesthetic was rendered as smooth and as satisfactory as though it were for an operation on some other part of the body Meyer also described how he used an intravenous saline infusion containing adrenalin to maintain a satisfactory blood pressure—a method more recently revived[22] in connection with spinal anaesthesia

The positive pressure method still lingers on in spite of the great amount

These differential pressure methods appeared to solve the immediate problem of pneumothorax by preventing the collapse of the lung But many surgeons, however, were baffled by the frequency with which patients who had been submitted to several hours of this anaesthesia gradually deteriorated and died or became apnoeic and pulseless when the positive pressure was removed Meyer describes an oesophagectomy carried out under positive pressure anaesthesia with nitrous oxide and oxygen at the end of which

the patient is taken out of apparatus with lips red, pure oxygen having been administered during last $1\frac{1}{2}$ hours as soon as the head is removed from the apparatus his hitherto red lips turned a deep blue The jaw was pushed forward, the tongue pulled out, and oxygen again administered Subcutaneous stimulation and intra venous infusion During the latter the patient expired, about ten minutes after completion of the dressings

Meyer felt that death might have been due either to general anaesthesia, haemorrhage or shock The general anaesthesia was in the hands of an expert and plenty of oxygen was given There was little bleeding, so shock remained a possible explanation, and this he believed was produced by accumulation of carbon dioxide in the blood Meyer in support of this belief said that Verworn, a then well known physiologist, had 'succeeded as early as 1892 in asphyxiating an animal by carbon dioxide retention while it was breathing pure oxygen'

Meyer also drew attention to Volhard s (p 70) instructive paper of 1908 in which it was shown that curarized dogs could be kept alive by continuous gentle insufflation of pure oxygen through a narrow rubber tube into the trachea with free escape of the oxygen round the tube The length of time animals could be kept alive in this way varied with the rapidity of the oxygen flow and hence with the efficiency of the carbon dioxide removal

It gradually became clear that carbon dioxide retention occurred when differential pressure anaesthesia was used, and that it was necessary to let the lungs collapse at frequent intervals by reducing the intrapulmonary pressure to atmospheric Some surgeons, in fact, indulged in rhythmic variations in pressure coinciding with the patient's respiration, amounting to what we would now call assisted respiration This would be done for short periods of time, reverting to positive pressure anaesthesia in the intervals

The following are taken from one of Meyer s papers [2]

The so called shock in these cases is evidently partly due to an accumulation of carbon dioxide in the blood In an exploratory thoracotomy of short duration such retention of the noxious gas is not sufficient to do injury But in the longer operations for instance the resection of the oesophagus the greater CO_2 accumulation and the added effect of the necessary blunt handling of the network of the pneumogastrics both acting cumulatively in the same direction is too great a strain upon the heart, and it gives out

A very important conclusion can be drawn from these experiences. It is necessary in the course of thoracic operations of long duration to interrupt now and then the

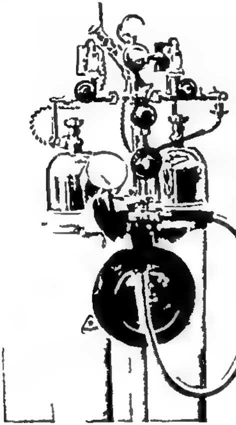


Fig. 57. Draeger Positive Pressure Apparatus (1918)

Features of this apparatus are an adjustable expiratory valve, a spring loaded plate bearing on the breathing bag, an injector device which allows air to be mixed with the gases in known proportions for the sake of economy, and drip vaporizers for ether and chloroform.

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CHAPTER IX

INSUFFLATION

An alternative form of positive pressure anaesthesia was successfully launched by Meltzer and Auer in the United States in 1909, when they published their perimental paper on 'Continuous respiration without respiratory movements'.[1] When studying 'the nature of the mechanism of the respiration in the presence of a double pneumothorax, while the animal is breathing compressed air by the Brauer method of over pressure' they discovered the fact that under certain conditions respiration can be carried on by continuous inflation of the lungs, and without any normal or artificial rhythmical respiratory movements whatever.'

The following extract from Meltzer and Auer's paper describes the details of their experimental method. Anaesthetists of to-day will be interested that once again the suggestion was made that curare be employed to abolish respiratory activity and reflex movement.

A longitudinal slit is made in the trachea of an anaesthetized dog or rabbit and a glass tube introduced down to the tracheal bifurcation. The protruding end of the tube is then connected with a pressure bottle by means of a T tube, the opening of the free branch of which is regulated by a screw clamp. The air which streams from the bottle under pressure partly escapes through the free branch of the T tube and partly enters the trachea and reaches the bifurcation from which it returns through the space between tracheal wall and tube and escapes through the slit in the trachea and through mouth and nose. It is essential that the tube should fill out two thirds of the lumen of the trachea, that the slit in the trachea be not too short and that the pressure of the air which enters the T tube should amount to about fifteen to twenty millimeters of mercury. The pressure within the trachea is, of course, much lower than that. In the connection between the trachea and the pressure bottle are interpolated a manometer, an ether bottle and a bottle with Ringer's solution to keep the mucous membrane of the trachea moist.* The essential point of the arrangement is that air is reaching the bifurcation under pressure and returns through another path than that through which it entered. When the air is thus circulating through the trachea the diaphragm descends, the thorax becomes moderately distended and the respiration mostly becomes very slow. The heart beats also frequently become dangerously slow. This danger, however, is easily obviated by an intravenous injection of one milligram of atropin, in a few seconds the pulse becomes frequent and remains so for many hours. The animal may receive now an intravenous injection of curare sufficient to completely abolish any spontaneous or reflex movements, its life is as safe as under regular artificial respiration. When the anterior thoracic wall is removed, the distended lungs are seen

* The authors did not illustrate the paper, but a few years later Meltzer showed (Fig. 58) a very similar apparatus he had devised for the thoracic surgery experiments of Alexis Carrel.

of experience and research during the last ten years, which have made rhythmic inflation of the lungs during induced apnoea, the almost universal method of anaesthesia for thoracic surgery For example, a positive pressure apparatus (Fig 57) is listed in the 1948 catalogue of a well-known European manufacturer[24] The apparatus is replete with every refinement that mechanical ingenuity can devise, but the troubles of positive pressure anaesthesia arising, as they do, from fundamental causes connected with the method, and being therefore inherent in it, occur with this elegant and ingenious apparatus as they did with the original Brauer apparatus

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CHAPTER IX

INSUFFLATION

An alternative form of positive pressure anaesthesia was successfully launched by Meltzer and Auer in the United States in 1909, when they published their experimental paper on Continuous respiration without respiratory movements [1] When studying 'the nature of the mechanism of the respiration in the presence of a double pneumothorax, while the animal is breathing compressed air by the Brauer method of over pressure' they discovered the 'fact that under certain conditions respiration can be carried on by continuous inflation of the lungs, and without any normal or artificial rhythmical respiratory movements whatever

The following extract from Meltzer and Auer s paper describes the details of their experimental method Anaesthetists of to day will be interested that once again the suggestion was made that curare be employed to abolish respiratory activity and reflex movement

A longitudinal slit is made in the trachea of an anaesthetized dog or rabbit and a glass tube introduced down to the tracheal bifurcation The protruding end of the tube is then connected with a pressure bottle by means of a T tube, the opening of the free branch of which is regulated by a screw clamp The air which streams from the bottle under pressure partly escapes through the free branch of the T-tube and partly enters the trachea and reaches the bifurcation from which it returns through the space between tracheal wall and tube and escapes through the slit in the trachea and through mouth and nose It is essential that the tube should fill out two thirds of the lumen of the trachea that the slit in the trachea be not too short and that the pressure of the air which enters the T tube should amount to about fifteen to twenty millimeters of mercury The pressure within the trachea is of course, much lower than that In the connection between the trachea and the pressure bottle are interpolated a manometer an ether bottle and a bottle with Ringer s solution to keep the mucous membrane of the trachea moist * The essential point of the arrangement is that air is reaching the bifurcation under pressure and returns through another path than that through which it entered When the air is thus circulating through the trachea the diaphragm descends the thorax becomes moderately distended and the respiration mostly becomes very slow The heart beats also frequently become dangerously slow This danger, however is easily obviated by an intravenous injection of one milligram of atropin in a few seconds the pulse becomes frequent and remains so for many hours The animal may receive now an intravenous injection of curare sufficient to completely abolish any spontaneous or reflex movements its life is as safe as under regular artificial respiration When the anterior thoracic wall is removed, the distended lungs are seen

* The authors did not illustrate the paper but a few years later Meltzer showed (Fig 58) a very similar apparatu he had devised for the thoracic surgery experiments of Alexis Carrel

to be immobile while the heart continues to beat with a regular rhythm If the above described arrangement is carried out properly the lungs retain their pink color,

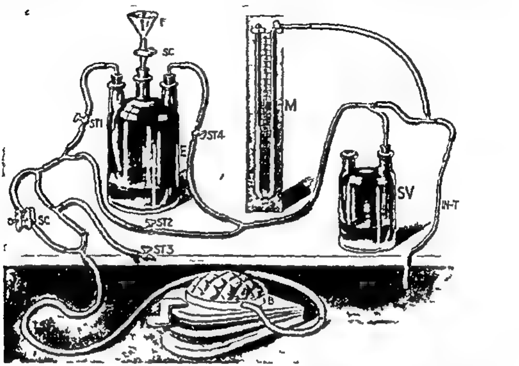

FIG 58 MELTZER AND AUER INSUFFLATION APPARATUS (1913)

A foot bellows provides a stream of air which by means of a series of stopcocks either passes through the ether bottle (E) or by passes it The air then passes to the tracheal tube (INT) M is a manometer SV is a mercury blow-off safety valve The author stresses the importance of tap ST3 which is used to interrupt the stream of air at regular intervals The end of the tube SV (calibrated in mm) is lowered beneath the surface of mercury in the bottle and thus controls the pressure and acts as a safety valve

the heart continues to beat regularly and efficiently for many hours and the blood pressure shows but little variation

They pointed out that the respiratory movements were essential only in so far as they facilitated the exchange of oxygen and carbon dioxide between blood and outer air *If the exchange could be effected without the respiratory movements, the latter could be dispensed with, without detriment to the animal*

In this technique a continuous stream of fresh air was blown into the lower part of the trachea The returning stream carried away with it the carbon dioxide Most of the respiratory effort thus became redundant and respiration was not only quiet but under suitable conditions ceased altogether

Though Meltzer and Auer were responsible for making this method widely known, they were by no means the originators of the method for in their own paper they mention that

Hook in 1667[2] maintained the life of a dog for an hour by continuous inflation of the lungs previously punctured at various places In the second place we have to

mention Nagel's communication[3] according to which the life of curarized pigeons were maintained by sending a continuous stream of air through the humerus which

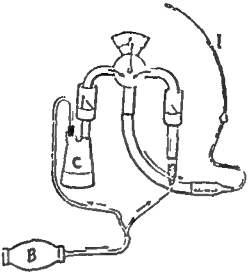

Fig 59 Barthelemy and Dufour's Endotracheal Insufflation Method (1907)

The first rather primitive use of an endotracheal insufflation method to permit the maintenance of anaesthesia from a distance in operations on the head. The authors were aware of the available alternatives such as Doyen's tube (Fig 128), rectal anaesthesia and the intranasal insufflation method, but wished to have the accuracy of control given by the Vernon Harcourt apparatus. The bulb was squeezed each time the patient took a breath; the flow of air was thus inadequate to prevent the entry of blood into the trachea (unlike Meltzer and Auer's method) and light packing of the pharynx with gauze was therefore used

B Hand bulb
C Chloroform container of the Vernon Harcourt apparatus
I Intubation catheter

in birds is connected with the air sacs. In this case the air escaped through the trachea. In both instances the air escaped through the paths opposite to those through which it entered. In our method the air enters and escapes through the trachea, although through the separate paths within it

There were, in fact, other forerunners to Meltzer and Auer in developing *the insufflation technique, both for clinical and for experimental use*. In 1907 Barthelemy and Dufour[4] had already evolved a somewhat similar method in an attempt to solve the problems of surgery around the head and face, where the presence of the anaesthetist and his mask was always unwelcome. A urethral catheter of a size which allowed free expiration around it was passed into the larynx of the anaesthetized patient, and an air and chloroform mixture from a Vernon Harcourt apparatus delivered directly into the trachea (Fig 59). Each time the patient took a breath the bulb of the inhaler was squeezed. This application of the endotracheal catheter method may have foreshadowed its future in European anaesthesia where tracheal insufflation was employed for operations around the head, whilst positive pressure anaesthesia became the routine for thoracic work

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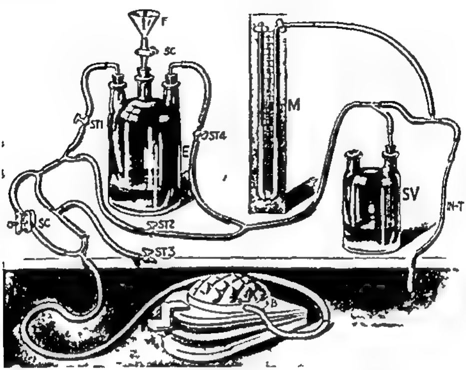

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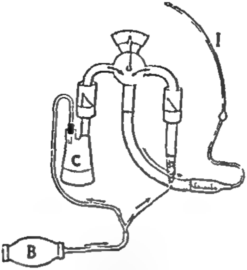

FIG. 59 BARTHELEMY AND DUFOUR'S ENDOTRACHEAL INSUFFLATION METHOD (1907)

The first rather primitive use of an endotracheal insufflation method to permit the maintenance of anaesthesia from a distance in operations on the head. The authors were aware of the available alternatives such as Doyen's tube (Fig [illegible]) rectal anaesthesia and the intranasal insufflation method but wished to have the accuracy of control given by the Vernon Harcourt apparatus. The bulb was squeezed each time the patient took a breath; the flow of air was thus inadequate to prevent the entry of blood into the trachea (unlike Meltzer and Auer's method) and light packing of the pharynx with gauze was therefore used.

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Volhard (p 64) had published[5] in 1908 the results of some experiments carried out a few years before * In these experiments he was able, by in

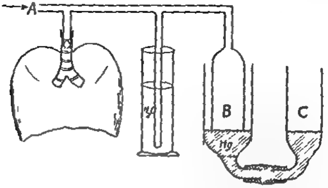

FIG 60 VOLHARD'S METHOD OF ARTIFICAL RESPIRATION (1908)

This method was used for artificial respiration in the curarized animal The tube in the animal's trachea is connected to the oxygen supply (A) The lungs inflate until the pressure within them is sufficient to force the mercury away from the bottom of the tube (B) Oxygen then escapes and the lungs deflate slightly the mercury develops a pendulum motion resulting in periodic inflation and deflation of the lungs The pressure within the lungs can be increased by raising the tube (C)

sufflating oxygen into the trachea, to maintain the life of an animal for a short time only Volhard believed this difficulty was due to ineffective carbon dioxide clearance He elaborated his apparatus (Fig 60) so that rhythmic inflation of the lungs was carried out by the stream of oxygen into the trachea With this modification of the insufflation technique, the animals showed none of the former ill effects

Volhard was so impressed with the success of his experiments with what he still called 'insufflation' that he thought that 'the fact that life can be maintained by insufflation of the trachea should be more widely known' As a result, several investigators took up this method, including no doubt Meltzer and Auer Thus Robinson reported[6] in the same year (1908) that he had performed six experiments by this method, for which he gives credit not only to Volhard, but also to Sollman, an American physiologist of some repute Oxygen was introduced by a catheter through a tracheotomy opening to the bifurcation of the trachea, while both sides of the chest were wide open

> The alveoli of a two thirds collapsed lung can thus be ventilated and the animal kept alive Not only is a direct access of oxygen to the partially collapsed alveoli thus established but a ready escape and flushing out of carbon dioxid is also provided through the tracheotomy wound around the catheter In one of two attempts I found it possible to maintain oxygenation by similarly introducing air and ether mixture by tracheal catheter with both chests opened and both lungs collapsed The secret of the success of these tracheal experiments with semi collapsed lungs is the absolute prevention of a dead space for carbon dioxid retention In order to avoid tracheo

* Volhard's pupil Hirsch had published part of these experiments in a thesis several years previously which had been widely abstracted

tomy and introduce air by the mouth, the lungs must be kept inflated by resisting the outflow of the air compression The aerating surface is thus increased and the ventilating air is kept in motion as in the tracheal experiments

Robinson did not believe that insufflation through a tracheal catheter would ever be a practical method in human beings because of the difficulty of inserting the tube He transferred his attention to the Brauer principle (Fig 39) of positive pressure Robinson was sarcastic, not only about the practical utility of the tracheal insufflation method, but that its origin was attributed to Meltzer and Auer A somewhat acrimonious exchange took place between Robinson and Meltzer as to who deserved credit for priority for the insufflation method Thus Robinson wrote [7]

In a paper read at Chicago before the Surgical Section of the American Medical Association in June 1908, I referred to the administration of oxygen through the trachea to the bronchial bifurcation, also to a similar deep introduction of air to the same point The idea of so using oxygen was suggested to me by Dr Sollman of Cleveland and by the publications of Volhard I was interested to substitute air to see if oxygenation of the blood could be maintained with the lungs in a state of collapse I found in my experiments that deep intratracheal administration of oxygen would maintain the normal pulse rate and respiratory movements in spite of removal of the front of both chests and in the presence of almost complete collapse of the lungs In substituting air under the same conditions, I found that it was necessary to keep the lungs at almost full inflation In other words aside from the necessity of passing a tube to the bifurcation of the bronchi, which is a procedure of considerable difficulty in the human though simpler in the dog, I could see no advantage in the method for practical purposes over the simpler use of a mask, as is shown in this small apparatus, or in the application of a peroral intubation tube such as I described in 1909 Meltzer and Auer have since utilized this intratracheal air method That the lungs may be so inflated with sufficient air exchange as not to disturb the circulatory functions, I became convinced in my experiments in the physiological laboratory of Professor Cannon at the Harvard Medical School in the spring of 1908 Had I then believed that this method would ever substitute the mask or cabinet method either in the human or in animals I should have continued with it But reminded by the throat specialist of the difficulty in introducing and maintaining instrumentation within the deep trachea I look with grave doubts on the application of this method to the human And knowing that the simplest mask method without irritation of the air passages is equally efficient in experimental thoracic surgery on animals I am not convinced that there is any advantage in the so called Meltzer Auer method

As we now know, while Volhard, and Meltzer and Auer deserve much credit for their important contributions, none of them could be called the originator of the insufflation method All three owed their ideas to earlier workers (see page 69)

Within a few years after his expressed disapproval of the method, however,

Robinson realized his mistake and transferred his interest once more to endotracheal *insufflation (see Fig 66)*

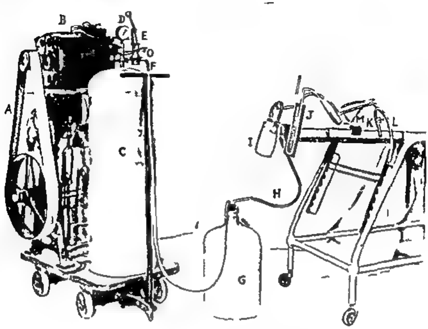

Fig 61 Elsberg's first Machine for Endotracheal Insufflation Anaesthesia (1910)

A A triple expansion pump driven by
B an electric motor The air was compressed into
C a reservoir cylinder with
D a pressure gauge
E Automatic cut off which stopped the motor at required pressure (60 lb per square inch)
O Regulator which maintained constant pressure in tube F
G Bottle containing sterile warm water to warm and moisten the gases
I Ether bottle with by pass
J Manometer
K Safety vent to permit lungs to be collapsed and also to control pressure of air entering trachea
L Tube leading gases into trachea

The possibilities of the insufflation method for human thoracic surgery were soon exploited by many American surgeons, prominent amongst whom was Elsberg, who became acknowledged as the expert on its clinical application His first machine in 1910 (Fig 61)[8] incorporated most of the essentials but was very bulky The light portable model described the next year *(Fig 62)[9] was the pattern which all future insufflation machines* followed Though the electric motor for the air compressor was situated in fairly close proximity to the ether container, no trouble with fires or explosions was recorded

Until this time it was usual for intubation for anaesthesia to be performed by the 'blind' digital method The epiglottis was pulled forward with the index finger of the left hand and the tube introduced with the right hand

Elsberg advocated that 'in the large majority of cases it may be preferable to expose the larynx with an appropriate speculum such as the Killian (Fig

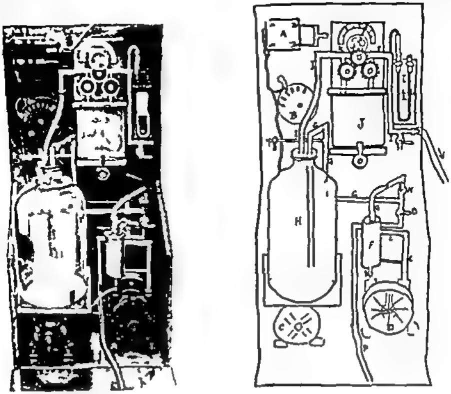

Fig 62 Elsberg's Portable Insufflation Apparatus (1911)

Description of apparatus

A Electric mains switch
B Rheostat controlling
C ¼ h p electric motor
D Blower air from which passes via tube E into
F oil filter and via tube G into
H bottle containing hot water through which the air bubbles
J Ether reservoir
K Hand wheel by which air is diverted into the ether chamber
L manometer which records the pressure
M Stop cock by which oxygen may be added
P Tube leading to foot bellows (in case of electrical failure)

In use stop cock M was left partly open to provide means for controlling the degree of positive pressure (20 mm Hg)
By opening stop cock T the air stream could be interrupted and the lungs deflated

125) or Jackson (Fig 144) instrument used in bronchoscopy, and then to introduce the tube with the larynx in full view He also advised that the stream of air be interrupted every two or three minutes, thus allowing the lungs to collapse (see p 64)

Many modifications of the original Elsberg apparatus were made, and we have chosen but a few representative examples for illustration In the United States insufflation anaesthesia became the method adopted for thoracic surgery and Janeway's (Fig 63 and 64),[10] Ehrenfried's (Fig 65),[11] and

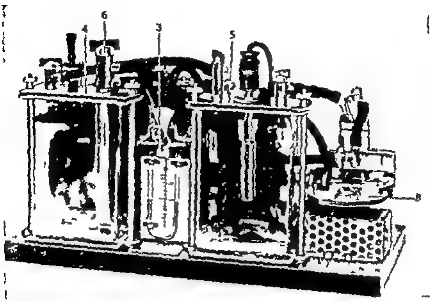

FIG 63 JANEWAY'S INTERMITTENT INSUFFLATION APPARATUS (1912)
Front view

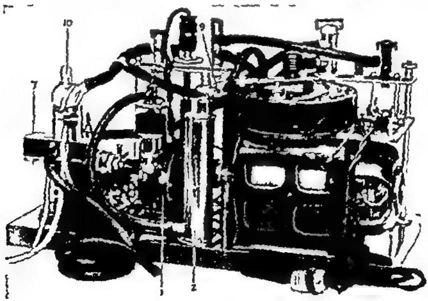

FIG 64 JANEWAY'S INTERMITTENT INSUFFLATION APPARATUS (1912)
Rear view

An electric motor (1) drives a blower (2) which sends a stream of air through a filter and silencer (3) A tap (4) diverts the air either through the ether vaporiser (6 and then over the warm water in an electrically heated jar (5) or directly through the latter and by passing the ether jar To increase the strength of ether vapour the manipulation of tap (7) causes the air stream to bubble through the liquid ether The valve (9) is opened at regular *intervals* by means of a cam and worm driven off the electric motor The air flow to the patient is thus mechanically interrupted at regular intervals the frequency of which may be adjusted The effect of this mechanism is to cause intermittent inflation of the patient's lungs simulating respiration The other function of this valve is to prevent the pressure from rising above a fixed limit The mechanism by which intermittent inflation of the lungs is produced should be compared with that in Fig 89

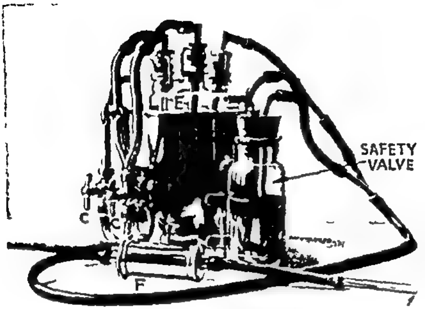

Fig 65 Tirrenspried's Insufflation Apparatus

This apparatus consists of a Wolffe's bottle containing ether surrounded by a copper hot water jacket A stream of air from a foot pump passes either over the surface of the ether or bubbles through the liquid the proportion of air by these routes being controlled by two taps The ether laden air now passes through a coil immersed in the water before being delivered to the patient A mercury blow-off safety valve prevents the development of excessive pressure Inserted in the delivery tube between the apparatus and the patient is a filter which prevents droplets of condensed ether from being carried over to the patient

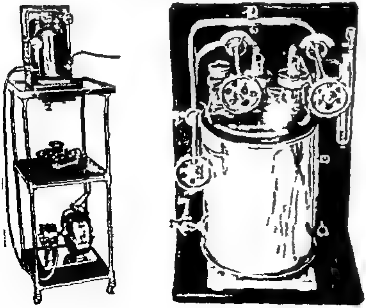

Fig 66 Robinson's Insufflation Apparatus (1912)

The apparatus consists of a Wolffe's bottle containing ether surrounded by a copper water bath standing on an electrically warmed plate the gentle heat from which prevents the temperature of the ether falling below 15 C or rising to its boiling point A stream of air from an electrically driven blower passes through the ether bottle the taps controlling the admixture of air and ether The tap on the left allows the anaesthetist to divert the air stream into the atmosphere whenever he wishes so allowing deflation of the lungs No safety device is provided to prevent excessive pressure The speed of the motor and hence the air pressure is controlled by a rheostat

Robinson's (Fig 66)[12] *apparatus were designed for that purpose In Britain,* as in Europe generally, positive pressure anaesthesia was the mode for this

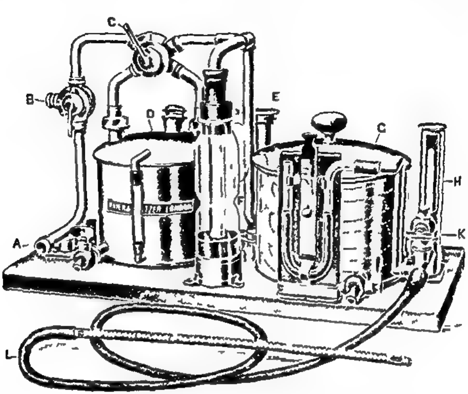

FIG 67 SHIPWAY'S INSUFFLATION APPARATUS (1914)

Here the ether is contained in a metal chamber (D) The air stream from an electrically driven pump may be mixed with oxygen and after admixture with ether vapour is humidified by passing through a moistening chamber (E) and is then warmed in a chamber (G) heated by hot water A blow off (F) is provided as is also a mercury manometer (I) and a thermometer (H) which indicates the temperature of the issuing gases No electrical heater is provided because of cost though Shipway makes the rather naïve suggestion that a spirit lamp is probably quite safe if properly guarded but I have not cared to run any risk with so much ether close at hand

branch of surgery and insufflation anaesthesia was chiefly used for nose and throat surgery Shipway's apparatus[13] (Fig 67) was intended for the latter purpose *Kelly of Liverpool did much to popularize insufflation anaesthesia* in Great Britain, but this was not primarily for chest surgery, and we have not reproduced or given a description of his apparatus because it so closely resembles Elsberg's

Meltzer's observation (Fig 58) was soon confirmed that periodic interruption of the air flow allowing momentary collapse of the lungs was essential if carbon dioxide retention was to be avoided Janeway's apparatus (Fig 63) provided this action automatically and, in fact, though called an insufflation

apparatus, the regular interruptions in flow and pressure made this method more like present day rhythmic inflation of the lungs

Kuhn in 1912[14] experimented with this new method of insufflation (see p 122), but considered it inferior to the combination of differential pressure and the wide bore tracheal tube Kuhn's view was general throughout Europe and the thoracic surgeons there continued to use differential pressure methods

Insufflation was originally intended to cope with the problems of thoracic surgery Rather incidently, Meltzer demonstrated that the outflow of air round the tracheal tube prevented the entry of debris from the mouth into the lungs This was noted by anaesthetists and surgeons in Great Britain, and the method soon became standard there for surgery in the mouth and nasopharynx, as indeed for the head in general

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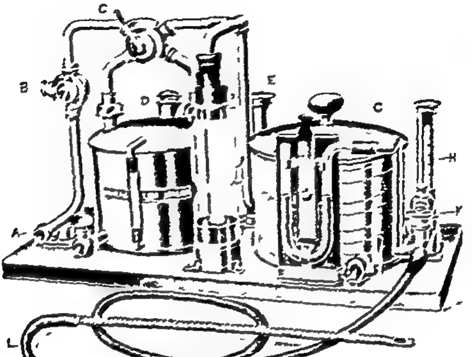

Fig 67 Shipway's Insufflation Apparatus (1914)

Here the ether is [illegible] a metal chamber (D). The air stream from an electrically driven pump may be [illegible] with ether vapour. It is humidified by passing through a moistening chamber (E), and is then warmed in a chamber (G) heated by hot water. A blow-off (F) is provided as is also a mercury safety valve (I) and a thermometer (H) which indicates the temperature of the issuing gases. No electrical heater is provided because [illegible] makes the rather naive suggestion that a spirit lamp is probably [illegible] not cared to run any risk with so much ether close at hand.

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lungs and the same inhibition of muscular efforts at respiration is obtained as by the intubation method. Professor Blake, for whom this cabinet has been made, has on the human subject demonstrated that such an inhibition occurred. During an operation for empyema in a child, whenever this device was utilized, the diaphragm and intercostal muscles remained at rest. This contrasted strongly with the respiratory efforts which occurred as soon as the valves were turned which permit of a change to the maintenance of a constant positive pressure. We desire to lay special stress on this point because the absence of muscular movements during operations in the thoracic cavity contributes in an important degree to the speed and ease of the operation.

This early advocacy of what is now called 'controlled respiration' appears to have escaped the notice of later investigators of this subject and the method was to lie dormant for some twenty five years.

Cotton, Boothby, Gwathmey and others successfully adapted the use of nitrous oxide anaesthesia to the endotracheal insufflation technique, making use of ether solely for the introduction of the catheter and then continuing with nitrous oxide. But as Janeway in 1913 observed:[4]

Such a method is wasteful of the anaesthetic, which under these conditions must be supplied in such excess that at each inspiration by the patient, there is very little dilution of the anaesthetic within the trachea by air, which, otherwise, would be drawn through the larynx around the intratracheal catheter. There must, in other words, be such a supply of nitrous oxide, that only a minimum amount of air is drawn in around the intratracheal catheter during inspiration. To supply such an excess of anaesthetic is not perhaps objectionable when ether is used, as ether is cheap in comparison to nitrous oxide, and further it is a comparatively easy matter to secure a sufficient degree of concentration of ether vapour to anaesthetize satisfactorily a patient by the usual intratracheal technique.

Janeway now described (see p. 123) in 1913 a method of economizing in the use of nitrous oxide which will be familiar to every anaesthetist to-day:

In order to overcome these difficulties in connection with anaesthesia by nitrous oxide, the writer has devised the little bag illustrated [Fig. 146]. It is tubular in shape possessing a double wall so that it is capable of distension whether fitted over the catheter or not. It is pulled over the latter to a short distance above its extremity, and after the catheter is inserted into the trachea, the bag is distended with air through the fine rubber tube attached to it, thus effectually closing the space between the outside of the catheter and tracheal walls. The patient may now breathe in and out through the intratracheal catheter, and when the external end of the latter is attached to a respiration bag, receive the nitrous oxide and oxygen directly from the tanks undiluted with air. ... The dimensions of the catheter are important. It must have a lumen of at least [illegible]/16 inch. The author has used a very thin walled, flexible metal tube covered with a piece of Penrose drainage tube.

Though Janeway gave himself the credit for inventing the device, it had already been described and illustrated by Dorrance (Fig. 138, p. 121) three years earlier. The illustrations of both Dorrance's and Janeway's catheters

CHAPTER X

EARLY AUTOMATIC DEVICES FOR RHYTHMIC INFLATION

OF the American surgeons, Green[1] had made great use of the rhythmic inflation method in experimental surgery His laboratory technique used a mechanical pump which rhythmically inflated and deflated the lungs through a tracheal cannula He noticed that this method frequently abolished spontaneous breathing and that this state of affairs gave a tranquil operating field to the experimental surgeon working within the chest In later years this observation was applied to clinical surgery[2, 3]

In working with the intralaryngeal cannula it was noticed that the alternating increase and decrease in intratracheal pressure produced an artificial apnoea which *largely eliminated the movements of the diaphragm The advantages of such an* elimination of movement during operation were so apparent that it induced the other of us (H H J) whose previous work had been done entirely with the negative and positive pressure cabinets to devise another cabinet* provided with a mechanism

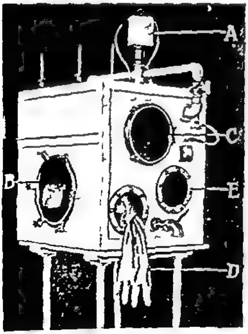


FIG 68 JANEWAY AND GREEN S RHYTHMIC INFLATION APPARATUS (1909)[4]

Though similar in general appearance to Brauer s original cabinet this one into which the patient s head is also inserted (B) is designed to produce apnoea and practically abolish all spontaneous respiratory activity A stream of air from a pump enters the box thus building up a positive pressure The valve (A) operated either by gear or cam from the electric motor opens at regular intervals allowing the pressure inside the cabinet to drop to atmospheric The frequency of the artificial respiration can be varied over a wide range as can the ratio of the duration of inspiration to expiration Port holes fitted with rubber gloves (D and E) are provided for the anaesthetist s hands and there is also a glass observation window (C)

Thus Janeway and Green accomplished in 1909 the method of anaesthesia which thirty years later was to become the standard technique for overcoming the problems incident on the widely opened chest Their method is identical with that now known as controlled respiration

which accomplished during operation a similar cessation of respiratory movements By means of this mechanism practically as complete inflation and deflation of the

* See Fig 68

gases exhaled from the patient's lungs It permits, in other words, of any desired amount of rebreathing from no rebreathing up to complete rebreathing of the expired air

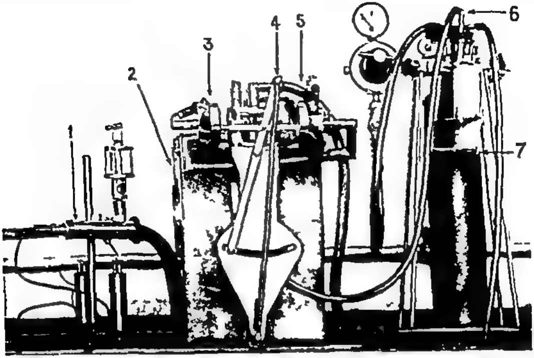
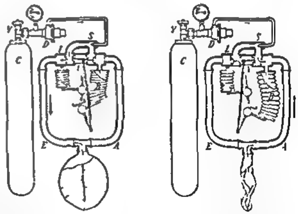


FIG 69 JANEWAY'S APPARATUS FOR ASSISTED OR CONTROLLED RESPIRATION (1913)

FIG 70 THE DRÄGER PULMOTOR (1911)



This apparatus was intended for artificial respiration for resuscitation in mines and in fires A mixture of air and oxygen is forced into the patient's lungs at a pressure of 20 cm H_2O during the inspiratory cycle The lungs are emptied by a negative pressure of -20 cm H_2O during the expiratory cycle

The left hand picture shows the lung (here represented by a rubber bag) being inflated Oxygen from the cylinder passes through the injector (S) entraining air and through the open valve (L) and the breathing tube (E) to the patient's lungs At the same time the gas mixture enters the concertina bag (B) When the pressure in the breathing tube has reached a certain level (say 20 cm H_2O) the now distended concertina bag operates the toggle mechanism and the apparatus is now as shown in the right hand picture When the spring and toggle mechanism kicks over into the expiratory position the valves are altered so that the suction produced in the injector mechanism now sucks the air out of the lungs closes the aperture through which the gases entered the breathing tube and instead of entraining air now discharges the contents of the lungs through the same aperture mixed with oxygen from the cylinder

We have, therefore in this apparatus a means of true artificial respiration with whatever gas (either air or nitrous oxide and oxygen) that is allowed to fill the respiration bag

could well be used in present-day manufacturers' catalogues, so little has design changed in the intervening years

If Janeway's place of honour among the pioneers of anaesthesia needs confirmation it is provided by his caution regarding the minimum diameter of his tube, though this is on the small side by modern standards, and on his use of the flexible metal tube made of spiral wire to prevent kinking, covered with Penrose drainage tube

Janeway also invented in 1913[4] an apparatus (Fig 69) which was designed to provide 'true artificial respiration synchronously with the patient's respiration, in other words, merely accentuating the patient's efforts of respiration'—an idea to be redescribed as recently as 1952[5] This apparatus was connected to the endotracheal catheter when the patient's chest was opened Inspiration alone was assisted, expiration being unhindered in any way

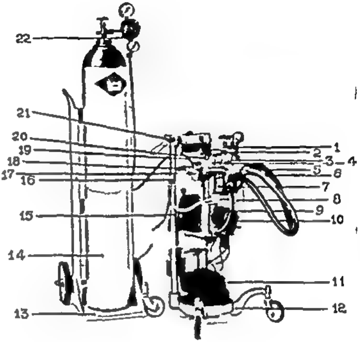
These results are accomplished by enclosing the respiration bag in an air tight aluminium box (2), attached to which are four valves a spring and two flaccid rubber tambours (3 and 5) A stream of air is allowed to pass alternately into the space around the bag within the box and outside the box into the room When the air passes into the box it increases the pressure around the respiration bag which contains the nitrous oxide and oxygen This increase of pressure is transmitted to the gases within the bag so that they are forced into the patient's lungs It must be borne in mind that there is, of course, no communication between the interior of the respiration bag and the space enclosed outside of the rubber bag by the aluminum box When the pressure within the box reaches a certain height for which the spring (4) may be set the air blows out the rubber tambour and reverses the position of the four valves This reversal of the valves occurs suddenly, inasmuch as the rubber diaphragm cannot start its movement until the resistance of the spring is overcome again the resistance offered by the spring is greatest at the extreme positions of its swing In the reverse position of the valves the current of air from the machine no longer enters the box, but exhausts in part into the room and in part into the space enclosed by the second tambour The stop cock controls the amount of air acting on this tambour, and, consequently, the time when the membrane of this tambour blows out, changing the valves back to their original position It will be appreciated that the speed with which the position of the valves is changed back to their original position depends only in part upon the second tambour If a minus pressure suddenly occurs within the aluminum box, this will tend to suck in the first tambour which of itself tends to change the position of the valves back to the first position permitting the entrance of air into the box Because of this fact there is a strong tendency for the increase and decrease of pressure within the box to be synchronous with respiration

The synchronism of the movement of the valves with respiration depends upon the fact that the changes in the pressure of the gases within the rubber bag transmit themselves to the space outside the bag and within the aluminum box and so to the rubber tambour The piece (1) is a valve permitting of the loss of any desired amount of the

From this description, it will be evident that Janeway's apparatus of 1913 is the forerunner of artificial respiration anaesthetic machines like the Spiro-

Fig 73 Lundy's Pulmonary Ventilator (1932)

This apparatus was designed for use in respiratory failure and in anaesthetic emergencies It consisted of a rotary blower (15) driven by an electric motor (11) The valve (4) driven by another electric motor (10) alternately connected the patient with the inlet and exhaust sides of the blower producing alternating negative and positive pressure within the lungs The speed of the motor moving the valve governed the frequency of the respiratory cycle and was controlled by *the rheostat (21) The degree of negative* pressure could be varied by valve (17) Excess pressure is prevented by automatic blow-off valves The mercury manometer (16) indicates the intrapulmonary pressure The apparatus incorporated a carbon dioxide cylinder (1) which could be used in conjunction with the main oxygen supply (14) The breathing tubes (5) end in a Y connector containing an expiratory valve (6) These tubes are shown connected with an endotracheal tube (9) The gases are moistened in the water bottle (8)



pulsator (Fig 74) and the Pulmoflator (Fig 90) as well as of resuscitators like the Pulmotor (Fig 70) and the E & J apparatus (Fig 71) In spite of the effectiveness of Janeway's apparatus it must have appeared at the time unduly complicated, for the simplicity and apparent effectiveness of the positive pressure method continued to hold the field

The adaption (Fig 53) by Bunnell in 1912[8] of the positive pressure method to nitrous oxide anaesthesia gave an indication of the technique which was to share popularity with the Tiegel-Henle method for the next twenty-five years Bunnell's method had the advantage of simplicity, requiring only the addition of a delicate spring loaded expiratory valve to convert a standard nitrous oxide and oxygen machine into one suitable for thoracic anaesthesia

Interest in machines for the application of automatic rhythmic artificial respiration passed for the time being from the field of chest surgery to that of resuscitation in asphyxia and drowning The Pulmotor[7] (Fig 70) is an example of an adaptation of the principles of Janeway's apparatus, while Lundy's machine, described in 1932[8], produced the same effect but operated in a different manner (Fig 73) By 1934, when Frenckner[9] surveyed the respiratory

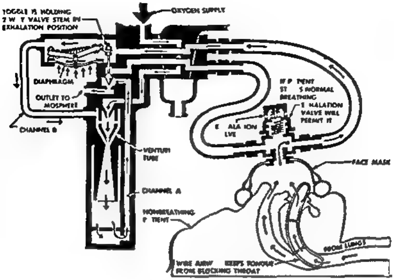


Fig 71 The E and J Resuscitator (Inspiratory Phase)

An apparatus designed to provide mechanical artificial respiration suction or oxygen for inhalation

The apparatus is shown in the inspiratory phase Oxygen from the cylinder passes through the venturi and channels A and B to the patient When a certain pressure is reached in the patient s lungs this depresses the diaphragm and trips the toggle mechanism lifting the two-way valve and thus starting the expiratory phase

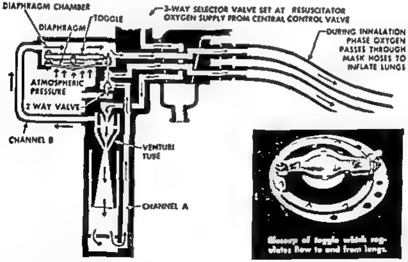


Fig 72 The E and J Resuscitator (Expiratory Phase)

Oxygen from the cylinder here passes through the venturi and escapes to the atmosphere causing a vacuum in channel B through which the gases are sucked out of the patient s lungs When the pressure in the system drops below the predetermined level the diaphragm rises and the apparatus reverts to the inspiratory phase once more

PART III

METHODS IN USE TO-DAY

problems of thoracotomy, the Pulmotor was the sole machine of this type in general use, being advocated for resuscitation only

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lung collapses completely and the expiratory stream is therefore stopped at a certain predetermined minimum pressure There is a regulable short or long pause after

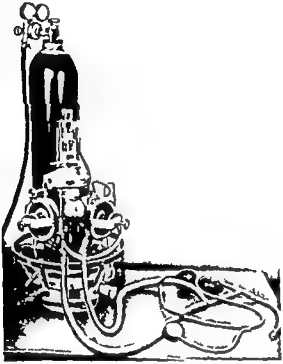

Fig 74 The Frenckner Spiropulsator (1934)

Note the endotracheal tube with cuff lying at the extreme right A hand bellows at the rear is for inflating the cuff while an aneroid manometer indicates the pressure within the cuff

expiration before the inlet valves are opened again and inspiration begins The basic principle in the automatic operation of the apparatus is that changes in pressure, regulable according to desire within the closed system determine the beginning and end of inspiration and expiration With a closed thorax these are brought about by the movements of the thoracic wall and the apparatus then follows normal breathing with *an open thorax, breathing is again regulated by the degree of expansion* of the lung and the frequency, depth of respiration and variations in pressure are varied according to the adjustment of the apparatus

The original Spiropulsator is illustrated in Fig 74 The automatic action of the machine depends upon a pressure sensitive magnetic control valve (the flasher)* which is so designed that the port through which the gases flow to the patient is either completely open or completely closed The action of the Spiropulsator is shown in Fig 75

Gas from the cylinder (1) passes through two reducing valves (2 and 3) and emerges at a constant pressure of 50 cm H_2O The equalizer (4), acting

* So called because of its direct descent from a similar device for automatically controlling the flashing of lighthouses and marker buoys

CHAPTER XI

MODERN AUTOMATIC DEVICES FOR RHYTHMIC INFLATION

IN his now classic paper[1] Frenckner draws attention to the work of Giertz, * who in 1916 had already confirmed experimentally the weaknesses of the differential pressure methods (see p 12) Frenckner repeated some of Giertz's experiments, and reported

In positive pressure narcosis even with relatively low values one sees how much the expiratory phase is hampered and what a strain the whole procedure is for the patient It is very easy to convince oneself on this point One must be absolutely well and strong not to feel worn out by an hour s breathing against a positive pressure of 7-8 cm H_2O without narcosis It may seem peculiar and improbable that such an insignificant obstruction as a back pressure of a few cm of H_2O should actually be able to tire out a patient This is however, undoubtedly the case and the explanation must be that expiration is the passive portion of respiratory work and the muscles intended for expiration are not accustomed to active work

He also noted that 'if during the operation one gives some rhythmic insufflation with positive pressure through the tracheal catheter the patient seems relieved '

Frenckner was 'convinced by such observations that the rhythmic introduction of air into the trachea under favourable circumstances would be the most ideal type of positive pressure breathing' and in 1934 designed the 'Spiropulsator '

This apparatus functioned according to the following principles

(1) The driving force is air, oxygen or the narcotic gaseous mixture, which is delivered under sufficiently high pressure (2) The apparatus works automatically according to pressure conditions within the lung so that with the thorax closed it follows the normal and occasional respiratory movements (for example, in coughing) but with a unilateral or bilateral open thorax it immediately takes control of the breathing with a frequency depth and pressure which are controllable in all the finest details

The gas cylinder (or other apparatus which delivers the compressed air or gaseous mixture), the spiropulsator the tracheal catheter and the lungs form a closed airtight system within which air or the gaseous mixture is conveyed to and removed from the lung through automatic valves The inspiratory air is admitted until a certain pre determined pressure is reached within the lung This maximum pressure closes the inlet valve at the same time as the passage is opened for expiration With a closed thorax expiration can take place freely while with an open thorax it is not desirable that the

* K H Giertz—at that time chief of the Surgical Department Sabbatsberg Hospital Stockholm—invited Frenckner to work with him on these problems Crafoord was then assistant to Giertz

ceases As spring (21) is set at a higher pressure it will have already opened valve (12) and the 'flasher' still keeps valve (6) closed, thus delaying inspiration and providing an expiratory pause

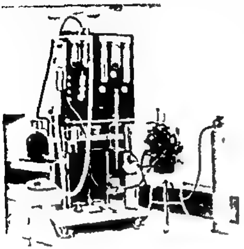

Fig 76

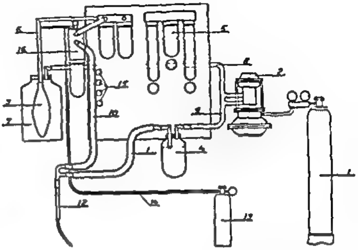

Fig 77

Fig 76 The First Crafoord Modification of Frenckner's Spiropulsator (1938)

A reservoir bag is incorporated from which the patient can obtain a breath even if out of step with the machine The patient's lungs are in communication with the bag only

Fig 77 Diagram of Crafoord's Modification of the Spiropulsator

The apparatus consists of a combination of the Frenckner Spiropulsator and an anaesthetic apparatus of the continuous flow type Nitrous oxide and oxygen from flowmeters flanking the mixing chamber (5) pass to the rubber bag (3) On the way to the inspiratory tube (10) the gases pass the spirometer (16) which indicates the volume of each breath The endotracheal connector (12) is joined to a 'T' piece to which are attached the inspiratory and expiratory tubes The expirations pass through (11) and bubble out of the tube which dips a few millimetres under the water in (4) thus acting as a one way valve The rubber bag (3) is rhythmically compressed by alterations in pressure of the air in the vessel (7) The pressure variations are produced by the Spiropulsator (2) driven by compressed air from cylinder (1) A cyclopropane cylinder (13) is also shown connected to the anaesthetic circuit

In order to start the new inspiratory phase, the 'flasher' chamber (8) is provided with a variable outlet pipe (11) through which air slowly leaks out during expiration until eventually the pressure in the chamber has sunk so low that spring (35) is able to overcome the tension of the 'flasher' spring and the 'flasher' reacts, opening the inlet valve (6) and closing the expiratory valve (7) Thus springs (21) and (22), acting on valves (12) and (18), control the pressure of inspiration and expiration The length of inspiration is controlled by the tap (5) which varies the rate at which gas is admitted, and the duration of the expiratory pause is controlled by valve (11) Manipulation of these two controls permits the frequency of respiration to be varied between one and sixty per minute Liquid anaesthetic from container (31) is vaporized by the heating coil (30) The gases are moistened in their passage through (32) and their temperature recorded by the thermometer at (33) The sensitive manometer (34) records the actual pressure within the machine

like a reservoir bag, allows the gas to pass from it during inspiration and stores it during expiration, thus providing a good flow of gas on inspiration The gas

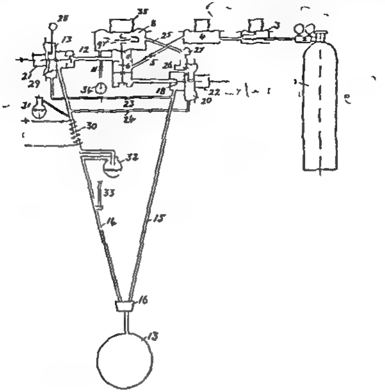

FIG 75 DIAGRAM OF SPIROPULSATOR

passes through the tap (5) (which controls the duration of inspiration), past the open valves (6 and 12) and via the inspiratory tube (14) into the lungs at (17) As the pressure in the lungs rises, this is transmitted to the diaphragm chamber (13) via the expiratory tube (15) and the branch pipe (23) When this pressure is greater than that exerted by the spring (21) (which controls the inspiratory pressure and can be regulated between 3 30 cm H_2O) valve (12) is closed Simultaneously, the pressure increase is transmitted to the valve chamber (20), pressing down the spring (22) which regulates the expiratory pressure within the limits 0–13 cm H_2O This is always set at a lower figure than the inspiratory pressure When this spring (22) is compressed, the gases pass via valve (18) into the 'flasher' chamber Valve (7) remains closed until the pressure of gas entering the chamber via (5) (and which cannot escape because valve (12) is closed) is sufficient to deflect the diaphragm (9) and open valve (7) at the same time closing the inlet valve (6)

Expiration can then occur the gas escapes and the pressure in both the expiratory (15) and the inspiratory tube (14) falls until it equals the setting of the expiratory spring (22) which then closes valve (18) and expiration

communication with the machine. The spiropulsator by alternately raising and lowering the pressure in the air-tight chamber outside the bag compressed the latter rhythmically forcing the gases into the patient's lungs. This apparatus had no soda lime canister and operated on what we would now call the continuous flow principle. The expirations of the patient passed out by means of tube (11) through the 'flasher.'

Though 'a prerequisite for satisfactory functioning of the machine was that the respiratory muscles of the subject do not work actively,'[3] the presence of the reservoir bag always enabled the patient to obtain a breath and thus prevented conflict between patient and machine. As a result the irregular disturbed breathing often seen with the earlier pattern was no longer evident and the patient could be quietly anaesthetized. 'As soon as the anaesthesia was deepened, all active respiratory movement ceased and breathing became automatically controlled by the spiropulsator.'[3]

When the experimental machine was found to work satisfactorily, a more compact commercial pattern was designed

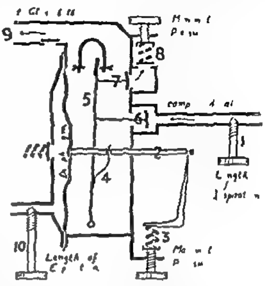

FIG. 80. THE FRENCKNER SPIROPULSATOR MECHANISM[4]

During inspiration compressed air enters via valve (6) passes via the outlet (a) to the plastic bulb containing the reservoir bag. A rise in pressure in the chest is transmitted to the interior of the valve pressing the diaphragm over to the left. The diaphragm moves the rod (2) over to the left against the resistance of the spring (3). The movement of the rod presses on the spring (4) and the weight arm (5) moves over to the left closing valve (6) and opening (7). Expiration then takes place via (8). The weight arm (5) is magnetically loaded so that valves (6) and (7) are either fully open or fully closed.

(Figs. 78 and 79), combining the Stille closed circuit machine[4] and the now perfected spiropulsator mechanism (Fig. 80).

From the diagram (Fig. 79) it is evident that there are two entirely separate circuits within the machine. One is the spiropulsator circuit maintaining rhythmic pressure variations around the bag. The other, the anaesthetic circuit, consists of the flow meters for nitrous oxide, oxygen and cyclopropane, the carbon dioxide absorber, the rebreathing bag and the connecting tubes. There is a constant flow of 500 c.c. nitrous oxide per minute through the injector mechanism which creates a negative pressure within the carbon dioxide absorber, drawing expired gases from the main rebreathing tube into the absorber. The fresh gases are brought to the patient by a small bore tube entering the circuit at the endotracheal catheter connection. The patient expires into the single wide bore tube connected with the rebreathing bag.

A high degree of absorption efficiency was claimed for this circuit arrange-

Although Frenckner stated that the spiropulsator would either supplement or supplant the patient's own respiratory efforts, Crafoord found[3] that the

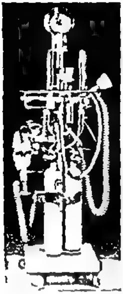

Fig 78

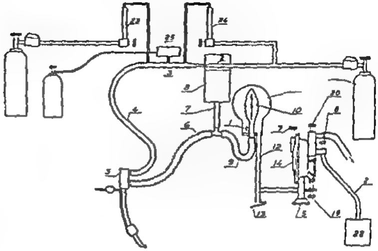

Fig 79

FIG 78 THE FIRST COMMERCIAL MODEL OF THE SPIROPULSATOR (1940)

This differed from the previous experimental apparatus by incorporating an absorber allowing cyclopropane to be used

FIG 79 A DIAGRAM OF THE SPIROPULSATOR ANAESTHETIC APPARATUS SHOWN IN FIG 78

A continuous flow of 500 c c per minute of gas from the nitrous oxide cylinder (1) passes through the injector (2) into the pipe (3) and thus creates a negative pressure in the soda lime canister (8) This negative pressure draws gas from the rebreathing tube (6) into the absorber (8) and thus provides a circulation of gas from tube (4) *into the patient s lungs and via tube (6) into the carbon dioxide absorber This is the principle of the Aga Stille* closed circuit circle absorber machine

Additional N_2O is added via the flowmeter (24) The flowmeters (23) and (25) control the quantities of oxygen and cyclopropane used respectively A narrow bore tube (4) takes the gases to the endotracheal connection (5)

During respiration the gases pass to and fro along the tube (6) into the reservoir bag (10) which is enclosed within the glass dome (16) Any excess of gas escapes via the spring controlled expiratory valve (11) Tube (12) connects the glass dome to the Spiropulsator valve (14) which receives compressed air from the compressor (21) Valves (17) and (18) control the duration of the expiratory and inspiratory phases respectively and valves (19) and (20) the maximal and minimal pressures produced

Valve (13) is kept open until artificial respiration is required This permits the anaesthetic machine to be used in the normal manner If it is closed however and the compressor started the Spiropulsator valve (14) produces alternating increasing and decreasing pressure in the glass chamber (16)

machine 'was ideal only if the patient s own breathing movements were entirely eliminated If the patient resisted the inspiratory effort of the machine with his own expiratory muscles the machine promptly changed over to the expiratory phase If, then, the patient tried to inspire rapidly, the flow of gas from the apparatus was insufficient to supply his inspiratory need

Crafoord, therefore, in 1938 interposed a reservoir bag between the machine and the patient s lungs (Fig 77) This rubber bag (3) was enclosed in an air tight chamber (7) The bag received the mixture of anaesthetic gases and formed a reservoir from which the patient breathed It had no direct

ment. Some doubt, however, is thrown on this claim by the now almost universal practice in Scandinavia of inserting a standard Waters' canister

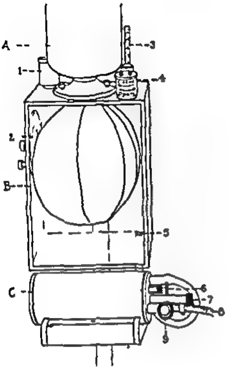

Fig. 83

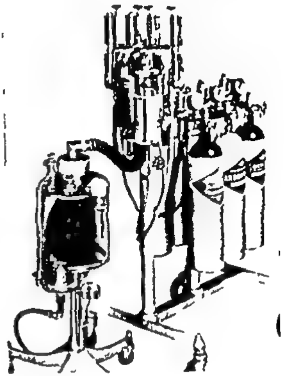

Fig. 84

Fig. 83 Mautz's Automatic Respiration Apparatus (1939)

The apparatus consists of a transparent air tight plastic box (B) enclosing the rebreathing bag of the closed circuit machine. (A) is the soda lime canister of the Heidbrinck apparatus and (C) the box containing the automatic mechanism. A compressed air supply is connected to the apparatus at (8). Valves (9) and (6) control the rate of flow of the air and admit it intermittently to the box at (5). The gases in the reservoir bag are thus forced into the patient's lungs by the inflow of compressed air into the box. The exhaust valve (7) then automatically opens the box to the atmosphere, the air escapes and expiration results. The manometer (3) indicates the pressure and the safety valve (1) prevents excessive pressure. The hand-controlled exhaust valve (4) provides immediate elimination of the automatic action and is used to throw the mechanism in and out of action and also to vary the maximum pressure attained. Mautz observes that Crafoord's machine, though differing mechanically, is similar in principle. Mautz does not give details of the mechanism of this apparatus.

Fig. 84 Mautz's Automatic Respiration Apparatus Connected to Heidbrinck Machine (1941)

into the breathing tube near the patient. The Waters' canister is clearly shown in Fig. 81 taken from the manufacturer's own post war catalogue.[5] The same thing is shown even more clearly in Fig. 82.[6] It seems that the Waters' canister, close to the patient, is really all that is necessary, and that the somewhat elaborate injector device is probably redundant.

The Spiropulsator found immediate acceptance in Scandinavia where at that time nurse anaesthetists were the rule, and became the instrument of choice for thoracic surgery and, in fact, has remained so there to the present day. Elsewhere it found little favour, the anaesthetist preferring to squeeze

FIG 81 AGA STILLE ANAESTHETIC APPARATUS WITH SPIROPULSATOR (1950)

The Waters canister can be clearly seen at the left of the photograph inserted between breathing tube and endotracheal tube A vacuum cleaner is being used as the source of compressed air to drive the spiropulsator At least one explosion has occurred through this practice cyclopropane either leaking or diffusing through the bag and getting to the sparking brushes in the vacuum cleaner

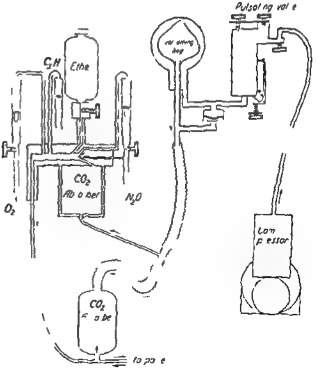

FIG 82 DIAGRAM OF SPIROPULSATOR SHOWN IN FIG 81

an apparatus (Figs 83 and 84) somewhat similar to the Spiropulsator for use in conjunction with the Heidbrinck closed circuit machine

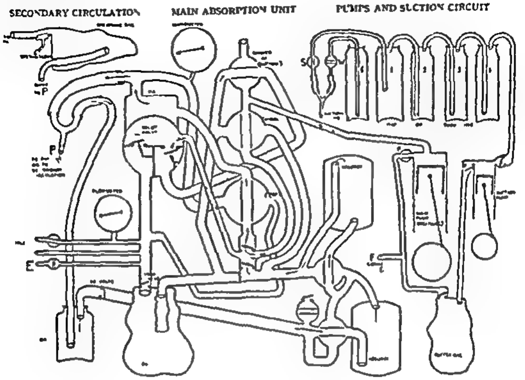

FIG 87 Pinson's Apparatus (1944)

This consists of two main parts the breathing pump circuit with the suction pump circuit and the main absorption unit

Two pumps are seen on the right hand side A ¼ h p electric motor works them both The speed of the breathing pump can be varied from 19 to 36 strokes per minute the stroke volume being also adjustable The suction pump draws the gases from the patient and any mucus blood or pus through a series of bottles which retain the liquids absorb the carbon dioxide and returns the anaesthetic gases into the main circuit The main absorption unit contains two canisters for the soda lime and is arranged on the single phase circle principle A diaphragm manometer is included to indicate pressure When the breathing pump is in action valves control the maximum pressures In addition to providing controlled respiration the apparatus may be used as a carbon dioxide absorber in which the gases are mechanically propelled round the circuit and through the soda lime In these circumstances the patient breathes spontaneously in and out of a secondary circulation bag near the face mask which is connected to the main absorption unit Though the movement of the bag will be synchronous with the pump the patient may be breathing with a different rhythm the anaesthetist can detect this by means of a stethoscope whose end is inserted into a small pilot connection to the main breathing circuit The arrangement of the secondary circulation bag is exactly like that of Jackson's apparatus of 1915 (Fig 188 p 145)

Unable to obtain a Spiropulsator during the German occupation of Denmark, Mørch[9] constructed an apparatus (Fig 85) for rhythmic ventilation which he used with a McKesson closed circuit machine Unlike the Spiropulsator the activating mechanism in Mørch's 'Respirator was a piston pump, and cycling was not controlled by the pressure changes within the chest The apparatus forced a certain volume of air into the patient's chest with each stroke of the piston, independently of the pressure changes within the

the bag himself It must be realized, however, that the original advocacy of the Spiropulsator was years ahead of practice current at the time, it was

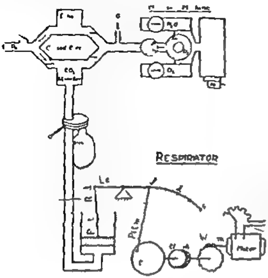

FIG 85 THE MØRCH RESPIRATOR

In this apparatus the rhythmic inflation of the patient's chest is produced by a motor-driven piston pump The volume of gas entering the patient's chest at each stroke can be varied by adjusting the point of attachment of the pitman to the lever Thus each stroke of the piston delivers a certain fixed volume irrespective of the pressure within the chest Safety valves are obviously necessary to prevent excessive positive or negative pressure Maximum positive pressure is controlled by the setting of the expiratory valve The pressure control on the rebreathing bag which is kept connected to the circuit is adjusted to 10 mm Hg The bag thus provides an additional buffer against sudden rises in pressure

The negative pressure produced by the withdrawal action of the piston is controlled by setting the McKesson *pressure dial between Off and O Should the piston* produce a negative pressure of more than −3 to −5 mm Hg fresh gases are delivered by the anaesthetic machine into the circuit

not until the outbreak of World War II that positive pressure anaesthesia in Britain and America gave way to controlled respiration

FIG 86 JAMES'S APPARATUS FOR CONTROLLED RESPIRATION (1931)

The operation of the bag is activated directly by an electric motor The frequency of cycling and the ventilation by the bag are determined by the anaesthetist and not by pressure changes within the patient

There were exceptions to this general attitude Mautz in 1939 described[7, 8]

a piston pump was the main mechanism (Figs 87 and 88) He incorporated in this apparatus many refinements, the main one of which was the ability

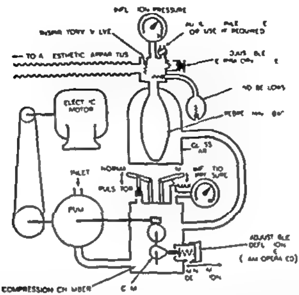

FIG 89 BLEASE'S FIRST PULMOFLATOR (1946)[15]

A constant supply of compressed air from a pump is led to a compression chamber connected to a glass jar containing the breathing bag A blow-off valve is operated by a cam which is connected by gears to the pump The minimum and maximum pressures are controlled by spring loaded valves The frequency of respiration is controlled by the speed of the motor The relative duration of inspiration and expiration is controlled by the characteristics of the cam and not by the pressures within the patient's lungs

to maintain constant suction without upsetting the anaesthetic mixture containing cyclopropane, by loss of gas from the circuit

Though the general design and execution of this apparatus is of a high order, it still suffers from the disadvantages inherent in a piston pump Since it was described no further reports of its use have appeared, nor to our knowledge has the apparatus been duplicated In any case, now that combinations of analgesics like pethidine with nitrous oxide and oxygen[1 13 14] are displacing the explosive and expensive cyclopropane, the need for a suction pump circuit in which gas loss is obviated has largely disappeared

In Britain interest in these machines has lately been fostered by the Blease Anaesthetic Equipment Co, who have designed two machines The first[15] (Fig 89), now superseded, suffered from the same disadvantages as a piston pump machine, because although such a pump was not actually used, the frequency of cycling was controlled by a motor independently of pulmonary pressures Reference to Fig 63 will show how closely this apparatus approximates in principle to Janeway's insufflation apparatus

The second Blease apparatus (Figs 90 and 91)[16], put on the market in 1950, resembles in its working principles the Spiropulsator Compressed air from

chest, though this volume could be varied at will The frequency of the respiratory cycle was unrelated to the pressure changes within the chest

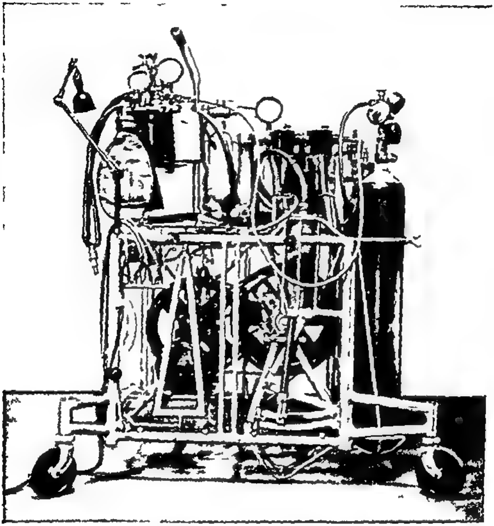

FIG 88 PINSON'S MACHINE READY FOR USE

With such an apparatus, the patient may require a larger tidal volume than estimated, and with a slow pump rate hypoventilation may easily result If the pump volume is considerably in excess of the patient's needed tidal volume the lungs may be held in inflation for an appreciable part of the inspiratory phase of the machine During this time the surplus gas is escaping through the expiratory valve

The apparatus shown in Fig 86[10] also depends on a simple pump mechanism, a corrugated bag taking the place of the piston of Mørch's apparatus

Pinson[11] in 1944 also devised an automatic respiration device in which

valve (10) can be increased by the lever O so that the pressure in the lungs does not fall to atmospheric. Should the anaesthetist wish to revert to manual

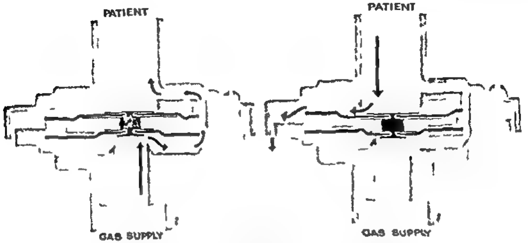

FIG 92 THE BURNS PRESSURE BALANCE RESUSCITATOR (c 1946)

The mechanism of this device contains a double diaphragm working in the horizontal position as shown against two ports of different sizes. The smaller lower one is for the entry of the gas supply, the upper larger one being on the side towards the patient. The pressure which pushes the diaphragm upwards and allows gases to flow to the patient is therefore higher than the pressure which moves the diaphragm in a downward direction shutting off the gas supply and allowing the patient's lungs to empty to the exterior

Left hand fig Inspiratory phase

A supply of gas at a preset pressure is connected to the inlet port of the valve. The twin diaphragm is lifted from its seating and gas flows through the valve to the patient's lungs

When the intrapulmonary pressure, i e the pressure on the patient's side of the diaphragm, is 80 per cent of that on the inlet side, the double linked diaphragm moves down, shutting off the inflow of gas, while at the same time allowing the patient's lungs to communicate with the exterior

Right hand fig Expiratory phase

This takes place by the normal elastic recoil of the chest wall and lungs. Once the diaphragm moves away from the upper seating a larger area of diaphragm is exposed on which the gas pressure on the patient's side now acts. When the pressure in the respiratory tract falls to 20 per cent of that on the inlet side, the diaphragm is pushed up, cycling occurs and inspiration commences once more

Since the inlet gas pressure is preset, no control over the inspiratory or expiratory pressures can be exercised. The sizes of the ports and the characteristics of the diaphragm are fixed during manufacture

controlled respiration at any time, tap Q disconnects the breathing tube K from the Pulmoflator and connects it to a bag R. The mechanism whereby the diaphragm and rod N flicks over is somewhat similar to that used for the same purpose in Janeway's apparatus (Fig 69). In Blease's apparatus the mechanism works as follows. The pressure in the main chamber rises and the diaphragm D is pressed outwards, stretching spring (12) and pulling rod (13) with it. Rod (16) is pulled over and disengages the pawl (14) from the wheel (11) which now turns round in a clock-wise direction because of the pull of the spring (12) on it. Valve (8) is therefore rapidly opened, and at this point the pawl (15) engages in its notch. The pressure in the main chamber begins to fall rapidly and the reverse cycle of events now occurs

Now that interest is once more alive to the value of automatic apparatus for controlled respiration, one type after another, each claiming to have

an electric compressor enters the main chamber A and into the glass chamber B connected with it The corrugated breathing bag T is therefore compressed, forcing its contents through the breathing tube (K) into the patient's lungs

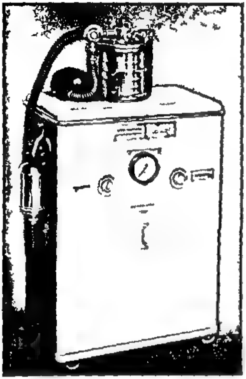

FIG 90 BLEASE PULMOFLATOR (1950)

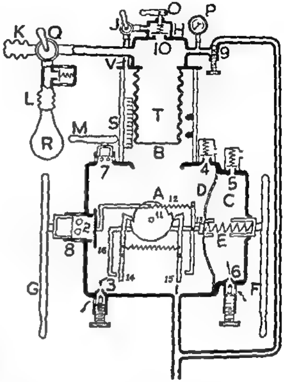

FIG 91 DIAGRAM OF BLEASE PULMOFLATOR (1950)

As the intrapulmonary pressure rises the diaphragm D is forced against the spring E until at a certain pressure the spring operated mechanism flicks over, opening the valve (2) and maintaining it in this position The pressure inside A quickly falls to atmospheric and the lungs deflate The spring E now pushes the diaphragm back and at a certain point the mechanism flicks over again closing valve (2) and the inspiratory cycle starts again The lever F controls the strength of the spring E and therefore the maximum pressure developed Tap (6) controls the length of expiration and tap (3) that of inspiration By closing valve (8) with its lever G the lungs can be held inflated Opening escape valve (7) by means of its lever puts the Pulmoflator out of action and allows the patient to breathe naturally When valve (8) is closed, opening and shutting of valve (7) is a means of rhythmically inflating the lungs A bleed valve (9) allows air to be added to the circuit A spill valve (10) allows excess of gases in the anaesthetic circuit to enter the main chamber outside the bag If the anaesthetist wishes the lungs to remain partially inflated at the end of expiration the spring pressure on the spill

to clinical anaesthesia[18, 19, 20] The Bennett resuscitator[21, 22] (Fig 93) is not far out of the experimental stage *Both these devices are extremely compact,*

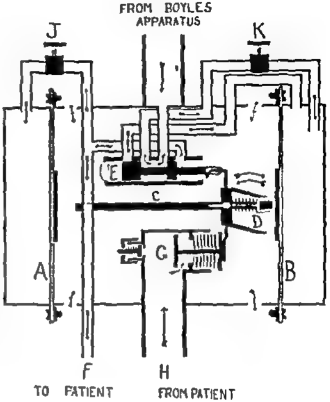

Fig 95 Williams's Automatic Breathing Attachment for Boyle's Apparatus (1952)

The following description is taken from the original paper[23]

The apparatus consists essentially of two stout rubber diaphragms A and B which act alternately on a central sliding spindle C. This lateral movement of the spindle disturbs the balance of an eccentric cam D which thus moves instantly from one extreme position to the other The cam is attached to a gas valve E which in one phase allows mixed gases to pass via the narrow rubber tubing F directly to the endotracheal tube or face mask while in its other phase the valve completely cuts off the gas supply and by the same movement complete expiration is permitted by the opening of a large bore expiratory valve G built into the apparatus the expired air passing up the corrugated rubber tube H and escaping by means of vents in the casing of the attachment The respiratory circuit is thus unidirectional so that dead space and carbon dioxide retention are reduced to a minimum In the prototype change of rate and depth of respiration are controlled by two screw-clips J and K only

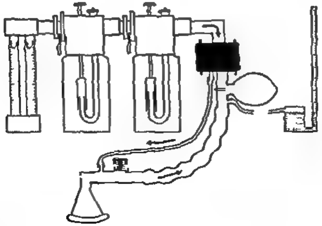

Fig 96 Williams's Automatic Breathing Attachment on Boyle's Apparatus

slipping into the pocket with ease These valves convert a continuous low pressure supply of gas into an intermittent *supply*, the maximum pressure and the length of each cycle being variable at will in the Bennett valve

advantages over the others, have made their appearance since the end of the war We have described here such machines as are interesting mechanic-

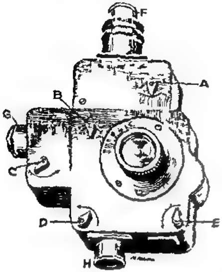

Fig 93 The Bennett Resuscitator (c 1946)

The compactness of this device can be judged from its overall dimensions some 6 inches square and 2 inches thick This illustration shows the external controls

A Inspiratory flow rate
B *Expiratory pressure*
C Expiratory flow rate
D Expiratory cycling rate
E Inspiratory cycling rate
F Outlet connected to patient
G Outlet for expired gases
H Inlet for gas coming from reducing valve

In addition to these there are also a cough relief valve to release the sudden high pressure in this circumstance and an emergency air inlet valve should the main gas supply fail

The ingenuity of design and the standard of workmanship of the inner mechanism is of the highest order and will repay study of the original publications by those interested in these details

ally or are easily available commercially There are, however, some, soon to be available *in this country, which in efficiency and compactness are*

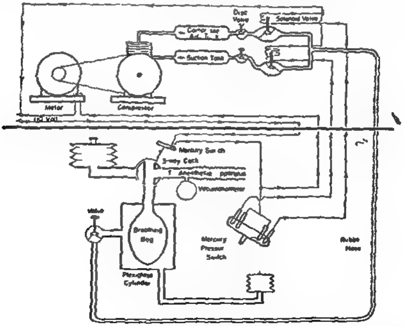

Fig 94 Mørch's Latest Respirator (1952)

This Respirator differs from any previously described in that the cycling and the action of the valves are actuated electrically Cycling is produced by the tilting of a mercury switch which actuates solenoid valves admitting gases under pressure for the inspiratory phase and providing suction for the expiratory phase

worthy of the closest attention Two of these in particular deserve mention The Burns Pressure Balance Resuscitator[17] (Fig 92) has already been applied

CHAPTER XII

THE DEVELOPMENT OF TRACHEAL AND BRONCHIAL INTUBATION AND OF THE CONTROL OF SECRETIONS

THE full development of present-day methods of anaesthesia for thoracic operations has depended upon the successful application of laryngoscopic and bronchoscopic methods for the correct and easy placement of endotracheal tubes and of endobronchial tubes and blockers.

The combination of skilful placement of tubes and blockers, with soundly constructed mechanical devices of various sorts for rhythmic inflation of the lungs manually or mechanically, and an understanding of the physiological processes involved, has brought thoracic anaesthesia to the present day level of refinement.

This chapter not only traces the development of methods of intubation and of the control of secretions, but it also fills in the spaces in the story of thoracic anaesthesia left in previous chapters. The list of instruments and of workers is not intended to be exhaustive, particularly of those within recent years.

1754 Benjamin Pugh,[1] a surgeon of Chelmsford, in common with other physicians of his day (see also Chapter X), became interested in resuscitation of the new born from asphyxia. He described (Fig 97)

> The Air Pipe as big as a Swan's Quill in the Infide, ten Inches long is made of a fmall common Wire turned very clofe (in the Manner Wire Springs are made) will

FIG 97 PUGH'S AIR PIPE (1754)

> turn any Way and covered with thin foft Leather, one End is introduced up the Palm of the Hand and between the Fingers that are in the Child's Mouth as far as the *Larynx* the other End external

Mørch's latest respirator illustrated above (Fig 94) ingeniously utilises electrical means for its actuation

The device described by Williams[23] (Fig 95) is clearly a compact version of Janeway's apparatus (p 81)

Williams's device is intended to be fixed between the flowmeters and the reservoir bag and breathing tube of the Boyle's or other continuous flow apparatus (Fig 96) When brought into use the continuous flow of gases from the apparatus is converted into an intermittent flow The ensuing rhythmic variations of pressure, ventilate the patient's lungs

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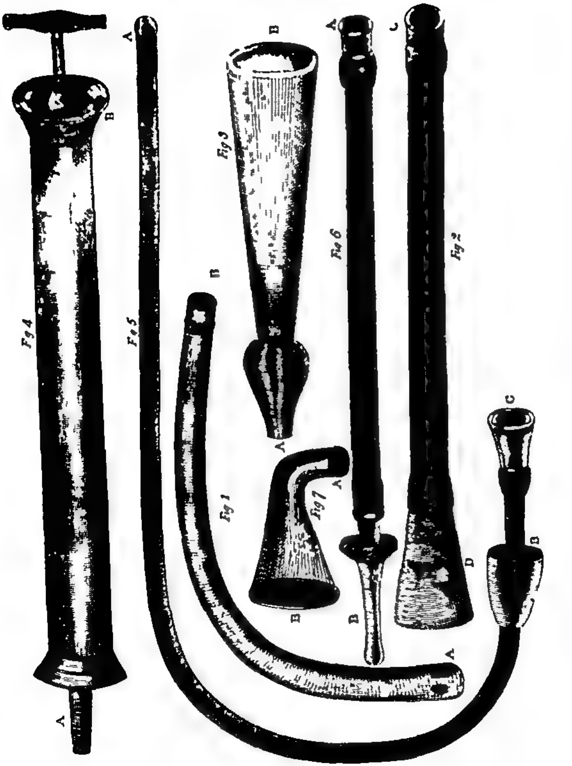


FIG 100 JAMES CURRY'S INSTRUMENTS FOR RESUSCITATION (179)
(See also Fig 13)

The first tube included in this chapter was thus constructed in the manner of the most modern—a fine wire spiral covered with a soft non traumatic

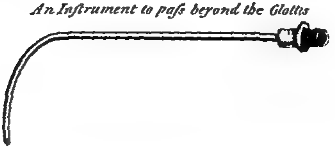


FIG 98 KITE'S INTUBATION TUBE (1788)

material This pattern of invention, and sometimes oft repeated rediscovery, runs through the history of endotracheal tubes just as it did through that of anaesthetic methods and apparatus described in previous chapters

1788 A tube designed to pass beyond the glottis was invented by Charles Kite (Figs 98 and 99)[2] He advocated the use of this tube for resuscitation The manner of using the tube is clearly described in the following extract from his *Essay on the Recovery of the Apparently Dead* (1788)

> The crooked tube bent like a male catheter is to be introduced through the mouth or one nostril into the glottis when on blowing through the mouthpiece or applying the bellows the lungs will be dilated

Kite reserved the use of this tube for cases in which the 'nostril tube' was ineffective or where respiratory obstruction occurred

1792 A complete set of instruments (Fig 100) was designed by James Curry,[3] a physician of Northampton, for the local Humane Society and was illustrated in his handbook on resuscitation, *Popular Observations on Apparent Death*, published in 1792 A second edition of this book[4] appeared

Fig 99 Kite's complete assembly—intubation tube attached to the elastic connection tube and ivory mouth piece

in 1815, but this time Curry remarks that the laryngeal tube and gullet blocker were included only for the sake of completeness (Fig 101) He

1806 The Royal Humane Society adopted a somewhat similar set of instruments[5] (see also p 32) (Fig 103) with the addition of a variety of connectors to be inserted into almost every orifice of the body These connectors included a silver tracheal tube Not only air, but *tobacco smoke, too*, was regarded as highly efficacious, especially when insufflated into the rectum

1806 The French obstetrician Chaussier[6] adapted one of these resuscitation cannulae for use in the newborn (Fig 102) (see also p 41)

1806 Bozzini[7] of Frankfort attempted endoscopy of the rectum and vagina with an apparatus which he termed a 'light conductor' It consisted of a leather covered tin stand, one-half of which was taken up by the candle, the other half having an aperture for the observer's eye (Fig 104) Various sized speculae were attached to the front of the lampholder depending on the anatomical orifice to be examined The Medical Faculty of Vienna condemned the instrument because of the poor illumination A later pattern of the endoscope (Fig 105) was fitted with an eyepiece and a concave reflector

1845 The use of tracheal tubes for asphyxia neonatorum would probably have died out after Leroy's damaging attack but for the enthusiasm of Depaul,[6,8] Chaussier's successor at the Maternite who produced a modified Chaussier tube (Fig 106)

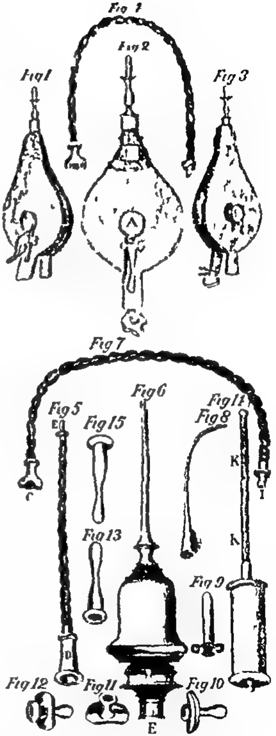


Fig 103 Royal Humane Society's Resuscitation Instruments (1806)
(See also Fig 11)
Note the silver tracheal tube (8)

then says, 'I believe that neither will be of much use, from the rigidity of the muscles in the greater number of cases of drowning, locking the jaws

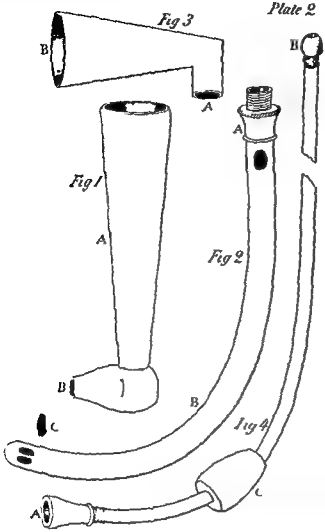


FIG 101 CURRY'S MODIFIED RESUSCITATION INSTRUMENTS (1815)

1 Boxwood nostril tube for inflation of lungs
2 Curry's improvement on Coleman's modifications of Kite's tube! Curry preferred a rounded tip and lateral openings to avoid trauma
3 Brass mount to connect cannula to bellows
4 Coleman's gullet blocker—leather covered spiral wire and ivory slider c Curry thought that rigidity of the jaw muscles would prevent intubation in most cases and that the nostril tube would be more practical The gullet tube was also used to wash out the stomach in laudanum poisoning

FIG 102 THE ORIGINAL CHAUSSIER TUBE FOR INTUBATION OF THE LARYNX IN ASPHYXIA NEONATORUM (1806)

so close as to render it impossible to introduce either with certainty' (see also p 35)

lens on to a reflector which projected the light down the tube in the observer's line of vision

1871 To facilitate operations on the mouth and larynx Trendelenburg[13] designed a combination of a tracheotomy tube with an inflatable cuff and anaesthetic cone (Fig 108) The anaesthetist was thus removed from the field of operation, and in addition the patient was protected against the aspiration of blood and debris At the suggestion of Trendelenburg, Schrötter[14] developed the use of bougies for the dilation of chronic laryngeal stenosis These

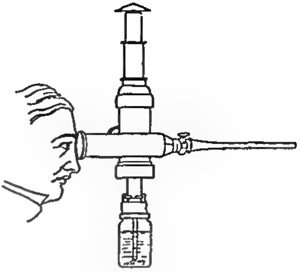


Fig 107 Desormeaux Endoscope for Examining Various Orifices (1853)

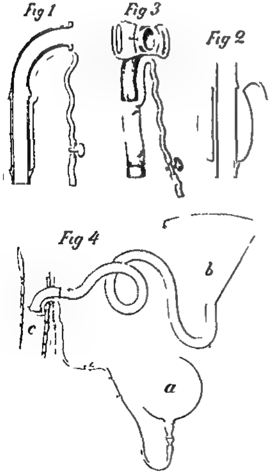


Fig 108 Trendelenburg's Tracheotomy Cannula with Inflatable Cuff (1871)

Figs 1 and 3 the tracheotomy cannula the cuff and the tube for inflating it
Fig 2 The cuff inflated
Fig 4 The assembled apparatus for anaesthesia The cannula is in place in the tracheotomy opening and is connected to the cone (b) by means of a flexible covered spiral wire tube Note the air space between the lint and the top of the cone The cuff has been inflated by means of the bulb (a)

As will be seen later, another pattern of Chaussier's tube was also produced by Ribemont[9] (Fig 112) (see p 111)

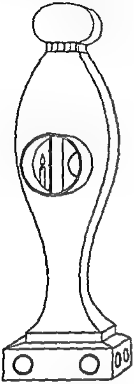


Fig 104 Original Bozzini Endoscope (1806)

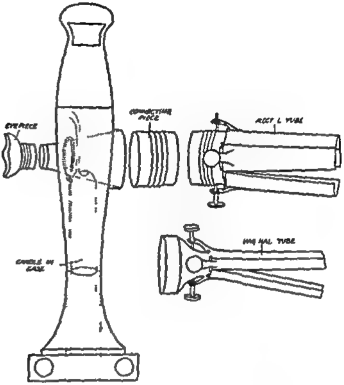


Fig 105 Improved Bozzini Endoscope showing Eyepiece Concave Reflector and Speculae

1848 Bouchut[10] and Snow[11] both made use of intubation, the former in an unsuccessful attempt to relieve diphtheritic croup and the latter in the course of anaesthetic experiments on animals (see p 45)

1853 The first successful attempts to examine the orifices of the body by direct vision were carried out about this time by Desormeaux[12] who has been called the 'father of endoscopy By now the somewhat primitive

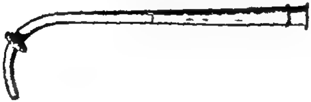


Fig 106 Depaul s Tube (1845)

endoscope of Bozzini had developed into the more elaborate one shown in Fig 107 The light from a 'gasogen burner was concentrated by a condenser

1878 : MacEwen of Glasgow[14] passed oral endotracheal tubes by the sense of touch in cases of oedema of the glottis He also used them for anaesthesia

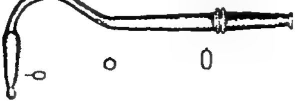


Fig 112 Riemont's Tube (18,3) (See also Fig 22)

during extensive operations within the mouth The tube was passed without anaesthesia of any sort The usual cough followed the introduction of the tube, but it ceased as soon as he received a few whiffs of chloroform, and long before he became constitutionally affected by the drug'

1885 Unaware of previous work on intubation by Bouchut and MacEwen, O'Dwyer,[18] of New York, experimented with intubation for diphtheritic croup

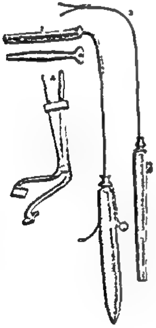


Fig 113

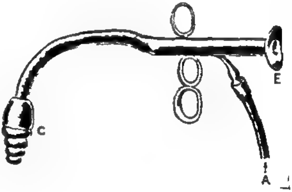


Fig 114

Fig 113 O'Dwyer's Tubes and Introducers (1885) (See also Fig 23)

Fig 114 O'Dwyer's Laryngeal Tube designed for use with the Fell Resuscitation Apparatus (c 1900)

Fell generally used a face mask or a tracheotomy tube with his resuscitation apparatus

Air from the bellows entered at (A) The conical end of this tube (C) was designed to produce an air tight fit when in the larynx The fingers of the operator's hand fitted into the rings provided and the thumb occluded the expiratory hole (E) during inspiration Expiration took place when the hole was uncovered

with great success He designed a set of self retaining tubes, the expanded upper end of which rested on the false cords (Fig 113)

Later O'Dwyer[19] designed a modified tube (Fig 114) for use with Fell's

bougies were also made hollow so that respiration could take place through them. The experience gained in passing these bougies and in designing the

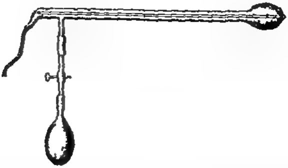


FIG. 109. WOLFFBERG'S ENDOBRONCHIAL CATHETER (1871)

Wolffberg in attempting to obtain gas from an isolated pulmonary segment in dogs adapted a Tarnier abortion catheter. The catheter was introduced through a tracheotomy opening into the left main bronchus. The cuff when inflated occluded the space between the tube and bronchial wall, though blockage of the upper lobe bronchus on that side not infrequently occurred.

most suitable sizes and curves was of the greatest value to later workers with endotracheal tubes.

In the course of experiments on the circulation and on blood gas analysis Wolffberg[15] in the same year adapted a Tarnier abortion cannula and balloon as an endobronchial tube in dogs (Fig. 109).

1865. Brunton of London[16] described an aural endoscope (Fig. 110), the principle of which was used by Voltolini in his tracheoscope. The source of lighting was daylight.

1875. Voltolini's tracheoscope[17] (Fig. 111) clearly descended from Brunton's instrument. Voltolini's was introduced into a tracheotomy opening. The trachea and the entrance of the main bronchi could then be examined.

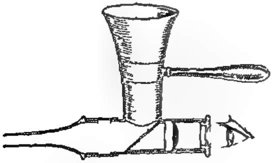


FIG. 110. BRUNTON'S AURAL ENDOSCOPE (1865)

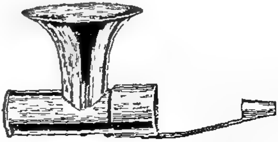


FIG. 111. VOLTOLINI'S TRACHEOSCOPE (1875)

1878. Ribemont[9] redesigned Depaul's tube after extensive experiments on cadavers (Fig. 112) (see also p. 42).

1892 Werigo's[22] endobronchial catheter for dogs was fitted with an inflatable cuff. Before use the catheter was inserted into a glass tube of the

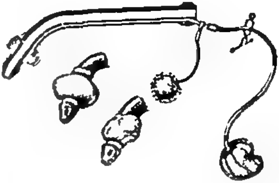


Fig. 118 Eisenmenger's Tube with Cuff (1893)

This was a hard rubber end tracheal tube whose shape followed that of Schrotter's bougies. Fitted to the end of the tube was a cuff inflated by a small hand bellows through a narrow bore connecting tube. Inserted on this latter tube was a small pilot balloon which indicated that the cuff was inflated. This seems to be the first invention of the pilot balloon though the device was yet to be rediscovered many times.

same internal size as the bronchus, and the pressure required for an airtight fit noted on the manometer (Fig. 117).

1893 A hard rubber tube with inflatable cuff and pilot balloon was designed by Eisenmenger[23] (Fig. 118) for oral surgery.

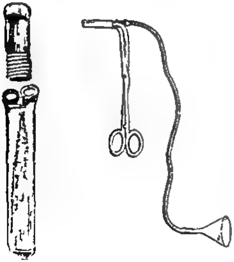


Fig. 119 Maydl's Tube (1893)

On the right is shown the complete apparatus which consisted of an O'Dwyer type tube resting on the larynx connected by tubing to a glass funnel containing a tuft of gauze on to which the chloroform was dropped. The introducing forceps are in position in the holes provided for that purpose. On the left is shown an enlarged view of the tube. It is triangular in section to fit the glottis, the expanded upper end lodging against the cords. A vulcanite connector screwed into the tube and enabled the tubing to be connected.

1893 Maydl[24] of Prague adapted the O'Dwyer tube for anaesthesia during oral operations (Fig. 119).

1895 A tube with inflatable cuff was designed by Tuffier[25] on the

bellows for artificial respiration—a combination named by Northrup the Fell-O'Dwyer apparatus (Fig 25) and which was adapted and advocated by Matas for thoracic surgery (Fig 26)

Fig 115 Annandale's Tube (1889)

This tube was made of gum elastic To avoid compression of the tube by the teeth a bite block or gag of hard vulcanite was provided which could be slid along the tube to the desired position

1889 An elastic catheter (Fig 115) with bite block was advocated by Annandale,[20] Professor of Surgery at Edinburgh, in preference to tracheotomy and to Trendelenburg's cannula and cuff

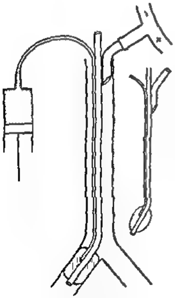


Fig 116

Fig 116 Head's Endobronchial Cannula (1889)

This consisted of a metal tube curved at one end to which was attached an inflatable cuff At the same time another tube of wider bore fixed to the top of the cannula lay in the trachea The latter allowed the *dog to breathe through one lung* whilst air samples were withdrawn from the other through the cannula

Fig 117 Werigo's Endobronchial Catheter with Inflatable Cuff (1892)

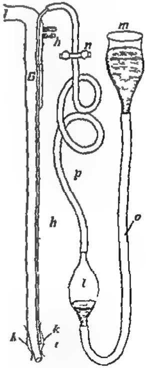


Fig 117

1889 While working on the regulation of respiration in dogs, Head[21] used an endobronchial cannula with an inflatable cuff (Fig 116)

O'Dwyer pattern for positive pressure anaesthesia in thoracic surgery (Fig 120)

1897 Another apparatus similar to that of Maydl, used by the French

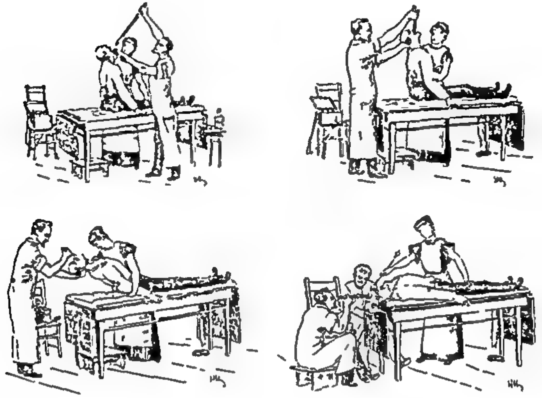


FIG 124 THE SWORD SWALLOWING METHOD OF OESOPHAGOSCOPY FROM A PUBLICATION BY VON HACKER IN 1896

surgeon Doyen,[6] utilized an O'Dwyer pattern tube and Trendelenburg's chloroform cone (Fig 121)

1895 Kirstein[7] designed the 'autoscope' (Fig 122) with which he developed the technique of examination of the larynx and trachea through the mouth Though at first an enthusiastic advocate he later concluded that it was a highly dangerous procedure, and warned against approaching the lower part of the trachea The source of illumination was an electric bulb in the handle, the light being reflected along the blade by a prism situated at the junction of handle and blade Kirstein used[8] his 'autoscope' in a manner rather different from that in which laryngoscopes are used to day (Fig 123)

1896 Killian,[29] 'the father of bronchoscopy,' enthusiastically followed up Kirstein's ideas and constructed a series of instruments which are the basis

Fig 120

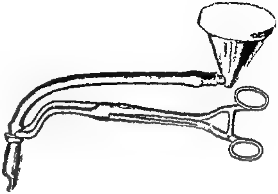


Fig 121

Fig 120 Tuffier's Tube with Cuff (1895)

A sectional drawing of the O Dwyer type tube designed by Tuffier for use with rhythmic positive pressure anaesthesia in thoracic surgery

As with the O Dwyer tub the expanded upper end rested on the cords the tube was connected to the anaesthetic apparatus by a length of tubing

An inflatable cuff was provided to make an air tight fit The measurements in millimetres show that Tuffier was well aware of the importance of an adequate airway

Fig 121 Doyen's Tube (1897)

Doyen s apparatus consists of an O Dwyer type cannula attached by rubber tubing to a Trendelenburg chloroform cone According to Matas the cannula closely resembled O Dwyer s though Doyen does not acknowledge this as the source of his design

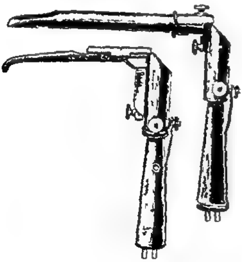


Fig 1 2 Kirstein's Autoscope (1895)

Fig 123 Kirstein's Autoscope in Use (1895)

that his tube not only prevented the disturbance that goes with vomiting in the middle of an operation, but also that pneumonia following inhalation

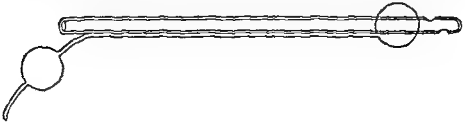


FIG 127 KAUSCH'S STOMACH TUBE WITH CUFF AND PILOT BALLOON (1903)

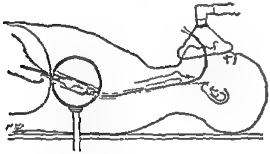


FIG 128 MACINTOSH'S OESOPHAGEAL TUBE WITH CUFF (1951)

of vomit was prevented Note the pilot balloon After a lapse of nearly fifty years a somewhat similar tube was described in 1951 (Fig 128) [33]

1905 Another example of the use of a cuff is provided by Loewy and Schrötter [34] They used a fine rubber catheter to obtain air samples from segments of the lungs in experiments on the circulation of blood in man (Fig 129)

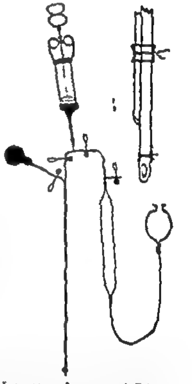


FIG 129—Loewy and Schrotter's endobronchial catheter and cuff and assembly for obtaining air samples The syringe was used to inflate the balloon Air samples were aspirated by the hand bulb on the left

The method of attachment of the cuff and its inflating tube to the endobronchial catheter is *shown in* the upper diagram

1900–11 Kuhn[35] designed a series of flexible metal tracheal tubes which he passed by sense of touch (Figs 130–133) Anaesthesia was administered either by Trendelenburg cone, by Kuhn's positive pressure apparatus (p 56) or by his closed circuit carbon dioxide absorption apparatus (see page 58)

1906 An endotracheal tube with cuff and pilot balloon was used experimentally by Green [37] The tube had metal ends and a flexible rubber centre section (Fig 134)

of those used to day (Fig 125) He removed, for the first time in history, a foreign body from a bronchus by bronchoscopy Killian developed the

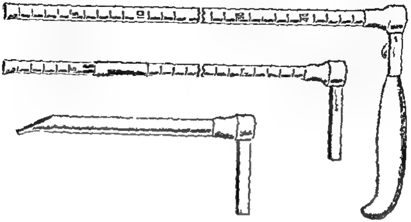


Fig 125 Killian's Bronchoscopes (1896)

present day method of inserting endoscopes, so different from the 'sword swallowing' methods[30] current at that time (Fig 124)

1898 Van Stockum's endotracheal tube[31] with cuff was used for nasal operations (Fig 126)

1903 The cuff ordinarily fitted on endotracheal tubes was used by

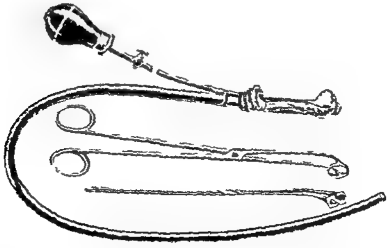


Fig 126 Van Stockum's Endotracheal Tube and Cuff (1898) for use during nasal operations Also shown are the introducing forceps

Kausch[32] (Fig 127) on a stomach tube to prevent vomit being regurgitated into the pharynx during operations for intestinal obstruction He claimed

1909 Meltzer and Auer's experimental work on 'Continuous Respiration without Respiratory Movement' using endotracheal insufflation, and Elsberg's

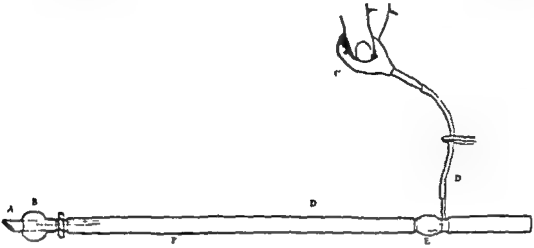


FIG 134 GREEN'S ENDOTRACHEAL TUBE AND CUFF WITH PILOT BALLOON (1906)

application of the method to human thoracic surgery gave a tremendous impetus to the study of intubation and laryngoscopic techniques In this

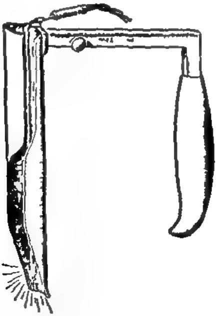


FIG 135 HILL'S SLOTTED LARYNGOSCOPE (1909)

technique of anaesthesia, narrow gum elastic insufflation catheters were used (see p 68, also Fig 151)

1909 Hill's laryngoscope[38] (Fig 135) and oesophagoscope (Fig 136)

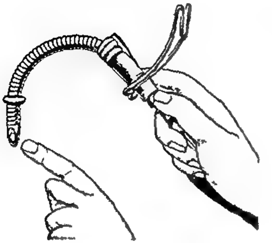


FIG 130

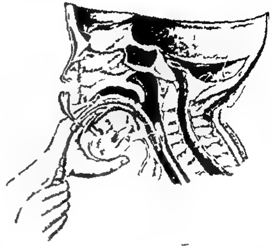


FIG 131

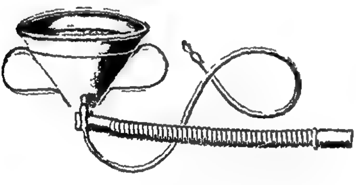


FIG 132

FIG 133

FIG 130 KUHN'S ENDOTRACHEAL ANAESTHESIA INSTRUMENTS (1900–11)[34]

Kuhn's endotracheal tube and introducer The tube is made of flexible metal At the tracheal end are lateral orifices so that a smooth rounded tip is obtained Near this end is a collar which makes an air tight fit in the larynx At the other end of the tube is a bite block for the teeth and through this end is inserted the introducer The wire face loop helped to keep the tube in position

FIG 131 The tube was guided into the trachea by the fingers in the mouth the forefinger of the left hand palpating the epiglottis and holding it forward In this illustration the tube is in place with the collar against the larynx The introducer is being withdrawn

FIG 132 To the tracheal tube is connected a Trendelenburg cone covered with flannel to receive the chloroform The small tube from the cone is inserted into the anaesthetist's ear so that the respirations can be heard

FIG 133 Administration of anaesthesia is in progress The listening anaesthetist has no doubt decided that too much chloroform has been administered the cone has been disconnected and the patient breathes air alone

between the laryngeal obturator cone on the Bell O'Dwyer tube (see Fig 114) and the larynx during a long operation

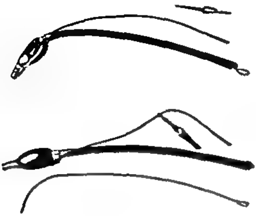


Fig 138

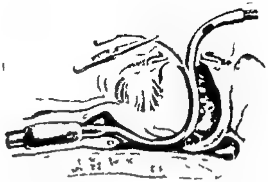


Fig 139

Fig 138 Dorrance's Endotracheal Tube and Cuff (1910)

This tube and cuff was evolved to provide an air tight fit with the trachea for efficient inflation of the lungs during thoracotomy

Fig 139 Dorrance's Tube in Place

Note the lateral hole outside the mouth for expiration Compare this illustration taken from Dorrance's paper with Fig 153

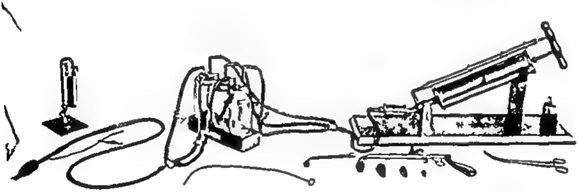


Fig 140 Dorrance's Outfit for Anaesthesia in Chest Surgery (1910)

His endotracheal tube and cuff replaces the Matas cannula shown in the foreground (Fig 26) Behind the cannula on the right is the pump for rhythmic inflation while in the centre are the bottles for vaporizing liquid anaesthetics Behind the endotracheal tube is the manometer for registering the intrabronchial pressure

1911 Morriston Davies[11] used a metal tube (Fig 141) and inflatable cuff with his positive pressure apparatus (see also page 63, Fig 54)

introduced the slotted blade This feature from then on appeared in nearly every laryngoscope and was rediscovered for bronchoscopes more than once

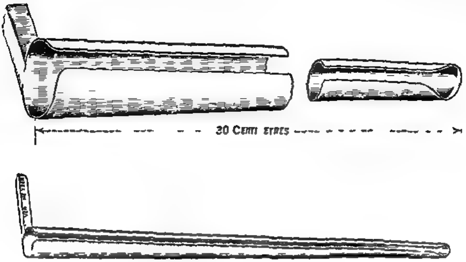


FIG 136 HILL'S SLOTTED OPERATING OESOPHAGOSCOPE (1909)

in later years (see Fig 162 and Fig 137) Hill was probably responsible for the first laryngoscopes with a segment of the spatula wall removed for easy insertion and removal of instruments (see page 123)

1910 Dorrance designed (Figs 138, 139, and 140),[40] and used, wide *bore endotracheal tubes, fitted with an inflatable cuff, in every way similar*

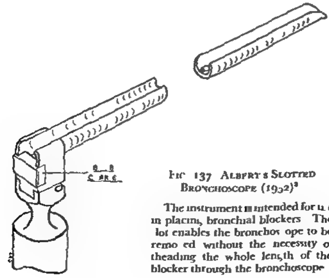


FIG 137 ALBERT'S SLOTTED BRONCHOSCOPE (1932)[3]

The instrument is intended for use in placing bronchial blockers The slot enables the bronchoscope to be removed without the necessity of threading the whole length of the blocker through the bronchoscope

to the modern pattern Dorrance's interest in these tubes was stimulated by the difficulty which he and others found in maintaining a good fit

1913 Chevalier Jackson[44] wrote his important paper on the correct technique for laryngoscopy for intubation He is shown (Fig 143) demon-

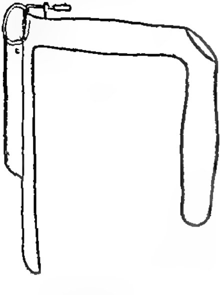


Fig 144

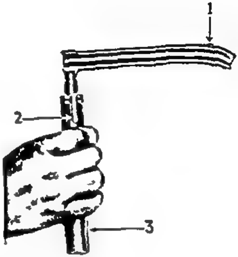


Fig 145

Fig 144 Chevalier Jackson s laryngoscope or laryngeal speculum with slide opening at side instead of on top This form originally devised for other purposes has advantages for the introduction of insufflation tubes because the slide may be left off altogether the insufflation tube being passed out sidewise in the removal of the laryngoscope (1913)

Fig 145 Janeway s Laryngoscope with Curved Blade (1913)

A battery is in the handle Unlike the present-day Macintosh laryngoscope the curvature was intended to direct the tube into the glottis rather than to expose the larynx by lifting the tongue and hence the epiglottis

strating the correct positions of the patient and anaesthetist A contemporary Elsberg apparatus can be seen in the background A Jackson laryngoscope is shown in Fig 144

1913 Janeway[45] designed a laryngoscope with a curved blade (Fig 145) The curvature was intended to direct the catheter into the larynx The instrument is designed to be held in the right hand during introduction Janeway used his instrument to pass gum elastic catheters fitted with his detachable inflatable cuff (Fig 146) Janeway's modification of the laryngoscope was to be later rediscovered by Miller,[46] Cassel[47] and Wiggin [48]

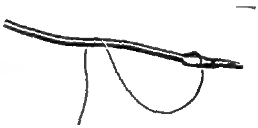


Fig 146 Janeway s Detachable Inflatable Cuff (1913)

This was devised to eliminate the waste of nitrous oxide with the insufflation method and to prevent the ingress of air (see page 79)

1920 Grappling with the problems of anaesthesia posed by maxillo-

1912 The first suggestion that secretions should be removed by suction was made by Kuhn[4] in 1905 In a later paper he advocated[11] the use of a

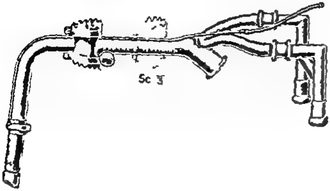


Fig 141

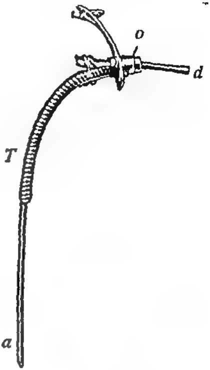


Fig 142

FIG 141 MORRISTON DAVIES ENDOTRACHEAL TUBE WITH INFLATABLE CUFF (1911)

FIG 142 KUHN'S TUBE WITH INNER CATHETER FOR SUCTION OR INSUFFLATION (191)

a

b

FIG 143 LARYNGOSCOPY FOR ANAESTHETISTS DEMONSTRATED BY CHEVALIER JACKSON (1913)

Fig a —The patient's head is being placed in position for laryngoscopy The pillow is removed th head is flat on the table and the anaesthetist is beginning to force the head into the extended position Th thumbs are on the forehead and the fingers are at the side of the head The direction of motion is shown by the dart

Fig b — The anaesthetist is lifting with the tip of the speculum in the direction of the dart The speculum is always held in the left hand The right hand of which the index has been protecting the upper lip has now received the catheter from the nurse

large bore endotracheal tube through which a smaller tube could be passed either for insufflating the gases or for suction (Fig 142)

to the lower end of the trachea The other of wider bore passed through a nostril into the pharynx only, and ensured a free exit for the gases It was

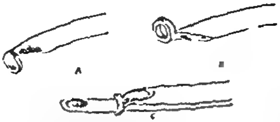


FIG 149 ROWBOTHAM'S MODIFIED TWO TUBE ENDOTRACHEAL METHOD (1923)

This was similar to the original method except that both tubes were passed into the larynx The illustration shows the method of cutting the wide bore rubber return tube and attaching it to the insufflation catheter

A End cut leaving a ring
B Ring everted
C Tube in place on catheter

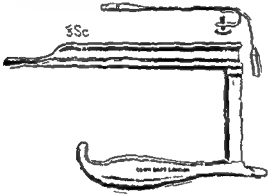


FIG 150 MAGILL'S ORIGINAL PATTERN LARYNGOSCOPE (c 1920)

FIG 151 MAGILL AND ROWBOTHAM'S DOUBLE ENDOTRACHEAL GUM ELASTIC CATHETER (1920)[18]

Below it is a narrow bore gum elastic catheter in general use in Britain since Meltzer and Auer's publication

noticed that occasionally the latter tube glided spontaneously into the larynx This phenomenon was further developed and described in 1928 by Magill as blind intubation [50] Magill's first laryngoscope is shown in Fig 150

1923 Rowbotham[51] modified the two tube method (*Fig 149*) *Both* tubes were now passed into the trachea under direct vision The two tubes were later made fused together[5] (*Fig 151*)

facial surgery for war injuries, Magill and Rowbotham[49] gradually progressed from the endotracheal insufflation technique using narrow gum elastic

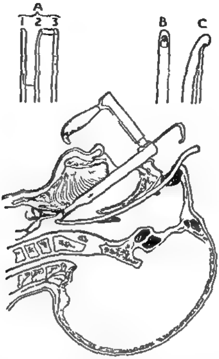


FIG 147 ROWBOTHAM'S METHOD OF PASSING A TRACHEAL CATHETER WITH A HILL'S LARYNGOSCOPE

The narrow bore insufflation catheter was passed through the nose and then using a Hill's laryngoscope was guided through the larynx into the trachea by means of the metal rod hooked into the eye at the end of the tube

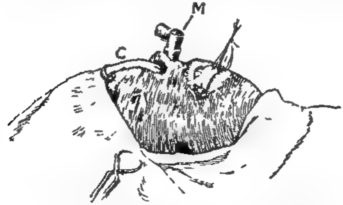


FIG 148 THE ROWBOTHAM TWO CATHETER METHOD IN USE

The narrow bore catheter (C) carries the anaesthetic into the trachea and the wide bore tube ending in the metal connection (M) directs the efflux of ether away from the surgeon and obviates any obstruction to the flow of gases This allows the mouth and pharynx to be packed with gauze

catheters to the wide bore inhalation method Originally two tubes were employed (Figs 147 and 148) One of narrow bore conveyed the gases

size 38F (12 7 mm outside diameter) for men, and 32F (10 7 mm outside diameter) for women In this paper Flagg tells how he had advocated in his

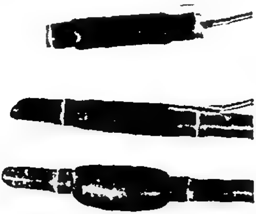


FIG 154 A REMOVABLE CUFF WHICH CAN BE SLID ON TO ANY DESIRED TUBE (GUEDEL AND WATERS 1928)[54]

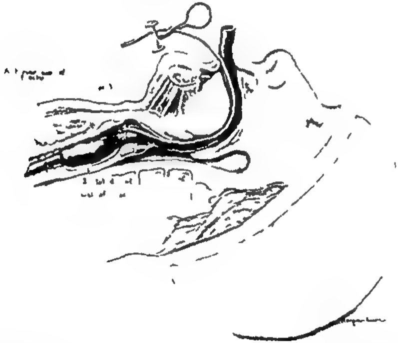


FIG 155 THE TUBE IN PLACE WITH CUFF DISTENDED (GUEDEL AND WATERS 1928) (Compare with Fig 139)

textbook in 1915 the then already well known endotracheal inhalation method through a single wide bore tube He was, however, shortly after, attracted for a time by the popular insufflation technique

1928 Guedel and Waters[54] introduced an endotracheal catheter (Fig 153–155) with an inflatable cuff which, though at that time they believed to be

1928 Flagg,[53] after trying the British double lumen catheter, decided that a single wide bore tube would be preferable With the help of Chevalier

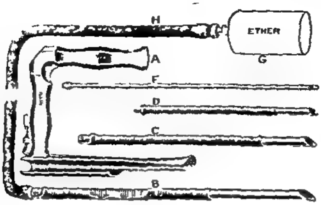


FIG 152 FLAGG'S APPARATUS FOR ENDOTRACHEAL INHALATION ANAESTHESIA WITH ETHER (1928)

The tube consisted of a flexible non collapsible spiral bronze wire portion covered with rubber drainage tubing This is attached to a bronchoscope type metal tip The tubes were made in three sizes and when fully introduced the tip lay 1½ inches above the carina (1 inch in children) A stylet was used for introduction Ether was given by punching four holes in the top of a standard ether can The patient drew in air via these holes and with it ether vapour (The Flagg can)

A Jackson laryngoscope
B Flexible spiral wire endotracheal tube covered with rubber with 9 mm bronchoscope tip
C 7 mm size tube
D 5 mm size tube
F Suction tube
G Ether can
H Connecting tubing

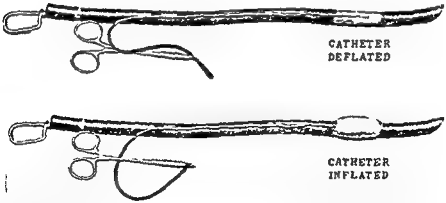


FIG 153 GUEDEL AND WATERS NEW INTRATRACHEAL CATHETER (1928)

The tube designed for use with carbon dioxide absorption anaesthesia was 14 inches long with $\frac{1}{16}$ inch thick walls and an inside diameter of ⅜ inch It was made of rubber or other composition free from tendency to kink The cuff either single layered and cemented in place or double layered and removable was inflated with a measured quantity of air from a syringe The catheter is shown deflated and then inflated Artery forceps are used to clip the tube leading to the cuff A metal stylet lies inside the tube to stiffen it while being passed

Jackson he determined that the largest tubes which could be used with safety to provide a watertight fit for oropharyngeal surgery (Fig 152) were

1932 Flagg[57] designed an improved pattern of laryngoscope which was the prototype of the anaesthetist's laryngoscopes to follow (Fig 157)

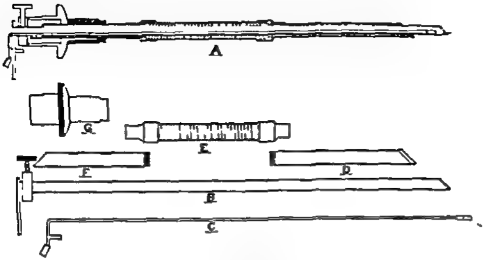


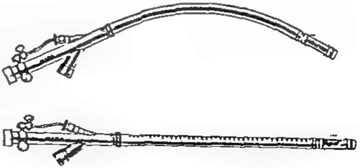
Fig 158 The Coryllos-McKesson Endotracheal Tube (1932)

The tube consists of two pieces of metal tubing 9 mm in diameter the distal one having a beak like a Jackson bronchoscope These are screwed into an intermediate piece of flexible wire coil (E) of the same diameter and 10.5 cm long covered with Penrose tubing The total length of this tube is 26.5 cm A rigid inner tube (B) with a distal light (C) projects slightly beyond the end of the endotracheal tube A short metal collar (G) placed around the proximal end serves as a bite block and has two holes for fixing tapes The tube is inserted under surface anaesthesia like a bronchoscope in the belief that spread of infection is particularly likely to occur during the induction of general anaesthesia A rubber or gum elastic urethral catheter is used for suction every five minutes during the operation and again before removing the tube

A Complete tube with bronchoscope and light in position
B Bronchoscopic inner tube
C Light
D and F Rigid metal parts of tube
E Flexible spiral wire part of tube
G Bite block

Fig 159 Frenckner's Tube with Cuff (1934)

Frenckner's tubes were made in various sizes for insertion into the trachea or bronchus for diagnostic or therapeutic purposes They were made in three pieces The rigid metal ends were attached by bayonet locks to the silk woven flexible centre section The distal end carried an inflatable cuff An extra entrance to the tube was provided for gas sampling or suction



1932 The Coryllos-McKesson tube (Fig 158)[58] was designed to reduce the deaths from atelectasis and spread of infection after thoracoplasty The tube not only ensured a good airway, thus avoiding anoxia and enabling slight positive pressure to be used, but also allowed secretions to be removed by suction

new, they later acknowledged to earlier sources Comparison with Figs 146 and 138 will show that they had been forestalled by Janeway in 1913, and by

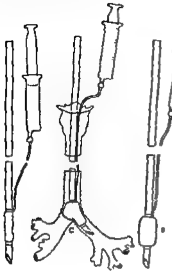


Fig 156

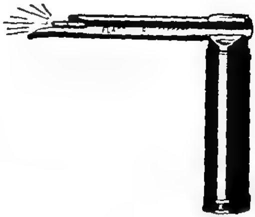


Fig 157

Fig 156 Gale and Waters Endobronchial Intubation for One Lung Anaesthesia (1931)

The inflated cuff blocks not only the bronchus intubated but also the bronchus on the other side thus effectively sealing off the lung operated upon

Fig 157 Flagg's Laryngoscope (1932)

The features of this laryngoscope were a handle and blade in one piece for strength a battery in the handle with bulb at the tip of the blade a longer blade than usual to allow for the occasional deeply placed larynx and a blade and lamp which can be sterilized by boiling (though Flagg himself was cautious enough to use alcohol only!)

Dorrance in 1910 Eisenmenger (Fig 118) had already in 1893 fitted an inflatable cuff to an endotracheal tube, while Head had used one in animal work in 1889 (Fig 116) Even as early as 1871 Trendelenburg had already fitted a cuff on a tracheotomy cannula

1931 Gale and Waters[56] made the first report of one lung anaesthesia for chest surgery (Fig 156) Endobronchial intubation was performed with a standard rubber and fabric Guedel-Waters endotracheal tube 14 inches long with an inflatable cuff The tube was moulded in hot water and given a lateral curve The tube was then inserted into the trachea with the tip of the tube towards the bronchus to be entered and the bevel towards the carina The tube was advanced slowly, stopping at the first feeling of resistance and the cuff inflated The intention was to avoid the 'pneumothorax syndrome by isolating the lung undergoing surgery A slight positive pressure was used to minimize mediastinal shift The advantages claimed were an immobile operating field, quiet respiration, the absence of shock from sudden pneumothorax and the prevention of secretions entering the trachea, although it seems that the prevention of the spread of infection was not the main aim of the originators of this technique

Griffiths that the main bronchus of the infected lobe might be occluded by an inflatable balloon, carried on the end of a catheter I have used this balloon eight times

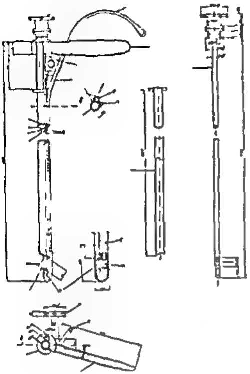


Fig 162

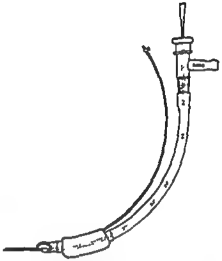


Fig 163

Fig 162 FRENCKNER'S BRONCHOSCOPE FOR THE INSERTION OF GAS SAMPLING ENDOBRONCHIAL TUBES (1934)
The optical system was similar to a cystoscope and as in the latter instrument a small lever near the light worked from a knob near the eyepiece guided the tip of the catheter into the bronchus Ureteric catheters were used When the catheter was in position the bronchoscope was removed by taking out the side slide

Fig 163 MAGILL'S ENDOTRACHEAL TUBE AND CUFF WITH T CONNECTION TO ENABLE SUCTION TO BE CARRIED OUT (1935)

and it has prevented all escape of pus from the affected lobe in seven I have, therefore, come to place a good deal of confidence in the balloon as a good means of avoiding this particular danger Insertion is not difficult for the Coude shape guides the tip into the desired bronchus An X ray film is taken immediately, and the depth of the penetration of the balloon can be immediately adjusted if necessary

1935 Magill, the leader of thoracic anaesthesia in Britain, introduced a series of instruments which were to have a marked and lasting effect on the development of thoracic anaesthesia He* was an advocate of suction as a means of removing secretions, and devised simple but effective means of doing this during the operation (Fig 163) Magill also developed further the principle described in Coryllos's paper of introducing tubes into the trachea and bronchus by means of an endoscope lying within the tube (Fig 164) By making endobronchial intubation comparatively easy and more certain, the principle of one-lung anaesthesia described by Gale and

1934 Frenckner[59] published his work on 'Bronchial and tracheal catheterization' describing his endobronchial catheters (Fig 159), broncho

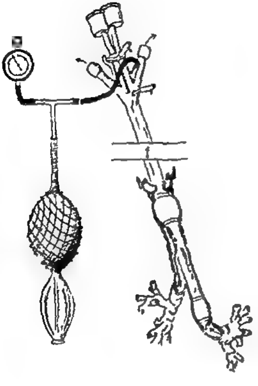


Fig 160

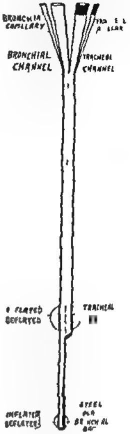


Fig 161

Fig 160 Frenckner's Double Bronchoscope for Bronchospirometry (1934)

The instrument is shown correctly placed with one cuff in the trachea and the other in the left main bronchus It foreshadows the Zavod and later patterns of bronchospirometric catheters in use to-day [60]

Fig 161 Zavod Bronchospirometric Catheter (1940)[60]

This instrument is made of latex rubber and is used for obtaining a spirometric record from each lung separately The catheter is passed with the aid of local anaesthesia through the larynx and advanced until fluoroscopy confirms that the small distal balloon lies in the left bronchus The larger proximal balloon lies in the trachea A small metal plate in the tip enables the end to be bent for easy entry into the bronchus and also to make the position of the tube visible on the fluoroscopic screen

spirometric technique (Fig 160) and the 'Spiropulsator' He also described a bronchoscope (Fig 162) to facilitate the insertion of endobronchial catheters, for gas sampling This bronchoscope had a slot similar to that shown in Figs 136 and 137 which permitted the removal of the bronchoscope without disturbing the catheter

1935 Archibald[61] described the use of bronchus blockers for the control of secretions during lobectomy

whenever sputum is profuse it is certain that this is one of the chief things to be feared several years ago I adopted the suggestion made to me by Dr Harold

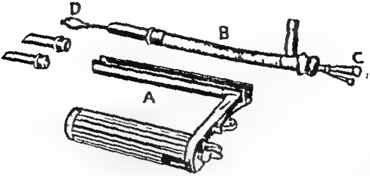
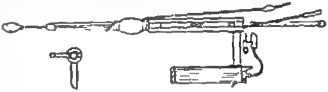


FIG 166 MAGILL'S BRONCHUS BLOCKER AND INSERTING TRACHEOSCOPE (1935)

This ingenious instrument consisted of a battery handle and tube carrier (A) the endotracheal tube (B) flexible in its central part and the bronchial blocker (D) combined with a suction catheter (C) In use the tube (B) was fixed to the holder (A) and the whole instrument used as a tracheoscope When the carina was seen the blocker was inserted into the bronchus and the balloon inflated The carrier A was then removed leaving the endotracheal tube and bronchus-blocker suction catheter in place

FIG 167 MAGILL'S MODIFIED BRONCHUS BLOCKER AND INSERTING INSTRUMENTS (1941)

The modification of the instruments shown in Fig 166 consists of a Brunning type extension to the endoscope so that the blocker can be placed within the bronchus more certainly and accurately The endotracheal tube now carries an inflatable cuff [84]



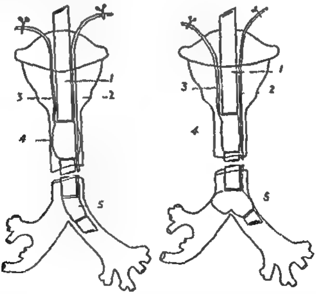


FIG 168 ROVENSTINE'S ENDOBRONCHIAL TUBE (1936)

The tube was made of woven silk and had two cuffs The catheter was moulded in hot water to give it a lateral curvature and passed into the trachea with the tip pointing towards the bronchus to be entered The tube was then advanced blindly until resistance was felt withdrawn a little and secured in place The upper cuff in the trachea was inflated first The lower cuff when inflated blocked the trachea across the carina When the upper cuff alone was inflated both lungs could be aerated The lower one was inflated and the upper one deflated when it was desired to collapse the lung on which the surgeon was working

Waters (Fig 156) became a practical routine possibility Magill's bronchus blocker (Figs 166 and 167) inserted under direct vision became the model for future blockers like Thompson's (see Fig 178)

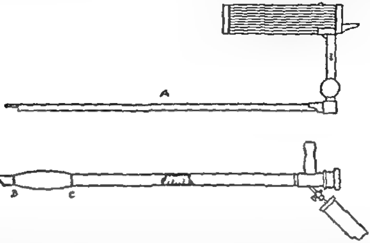


FIG 164 MAGILL'S ENDOBRONCHIAL TUBE AND BRONCHOSCOPE (1935)

The endobronchial tube consists of fine spiral metal tubing covered with close fitting thin rubber tied in three places The piece between the two fastenings (B) and (C) forms the cuff The latter is inflated by means of a syringe (S) the air from which passes to the cuff through the fine metal tubing forming the spiral In later years the spiral tubing was given up in favour of spiral wire and the cuff inflated by a small bore connecting tube (see Fig 165) Into the lumen of the tube was inserted the endoscope (A) which provided illumination from a battery in the handle The cuff when inflated occluded the trachea and the bronchus of the other side

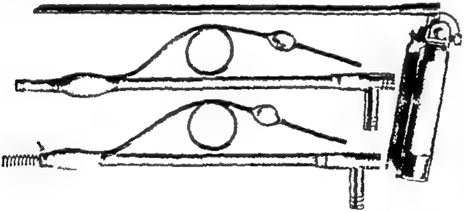


FIG 165 MAGILL'S ENDOBRONCHIAL TUBES (LATER PATTERN)[64]

The tube intended for the left bronchus has the spiral wire entirely covered with rubber That intended for the right bronchus has the spiral wire beyond the cuff left bare so that although the tube may be located within the right bronchus the right upper lobe is not obstructed when the cuff is blown up A recent modification has taken place Rubber tubes have been substituted for the rubber covered spiral ones They are of the same length and are used in the same way i e threaded on a bronchoscope

1936 Rovenstine[65] also recommended endobronchial intubation and one-lung anaesthesia, not so much to control secretions as to secure a quiet operative field for the surgeon (Fig 168) Rovenstine also pointed out that apnoea and controlled respiration were essential during one-lung anaesthesia

In the belief that endotracheal intubation was a manoeuvre requiring the exceptional skill of 'a clever and practised bronchoscopist,' Crafoord[66] designed

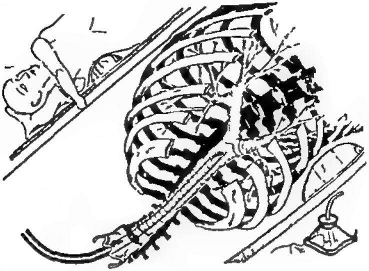


FIG 172 THE POSTURE ADVOCATED BY BEECHER TO PREVENT SPREAD OF SECRETIONS (NOSWORTHY 1941) An endotracheal tube without a cuff is used The secretions collect in the face mask

an indirect introducer (Fig 169) for the tube A striking similarity is seen between this instrument and the one (Fig 170) designed by Leroy just over a hundred years before [67]

1938 Blocking of a bronchus with a ribbon gauze tampon was used by Crafoord[61] (Fig 171) for the control of secretions

1940 Beecher[68] showed how spilling of secretions from one lung to another easily occurred when the patient is placed in the usual lateral position with the diseased lung uppermost He advocated a posture (Fig 172)[64] in which all the secretions from both the upper and lower lung drained into the trachea and so to the exterior (see also Fig 173)

1941 Nosworthy[64] published an important paper on thoracic anaesthesia In this paper he reviewed current clinical practice From this time onwards there was more or less unanimity of opinion among anaesthetists and thoracic surgeons that the problems of thoracotomy were best overcome by a combination of controlled respiration, tracheal or endobronchial intubation or blockage, posture and suction

1943 Though not the first to employ a curved blade on a laryngoscope Macintosh introduced [*] a technique of laryngoscopy at that time believed to be new His laryngoscope had a blade that was markedly curved (Fig 174), the tip of which was inserted into the vallecula between tongue and epiglottis By elevating the tongue the epiglottis was pulled out of the way and the larynx exposed Not only did this make laryngoscopy easier still, but by

Fig 169

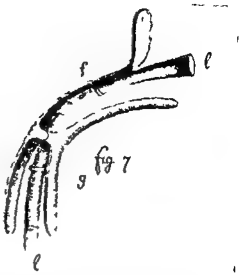


Fig 170

Fig 169 Crafoord's Indirect Endotracheal Tube Introducer (1938)

The instrument consists of lingual and palatal blades with which the jaws are propped apart and the tongue brought forward The inner ends of the two blades are then so adjusted that the larynx between them can be seen in a mirror fitted in the curvature of the palatal blade The tube is now passed between the cords

Fig 170 Leroy's Endotracheal Tube Introducer (1827)

When the palatal and lingual blades are in position the tube is directed by the guiding rings into the larynx

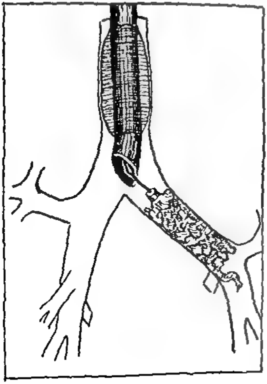


Fig 171 Crafoord's Bronchial Tamponage (1938)

The tampon is inserted through an ordinary bronchoscope and when in place a tracheal tube with cuff is inserted into the trachea This illustration is taken from Nosworthy's paper in 1941

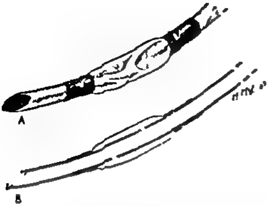


Fig 175

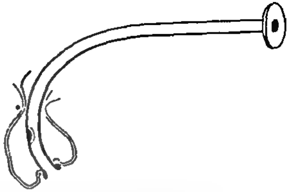


Fig 176

Fig 175 Mushin's Self inflating Cuff (1943)

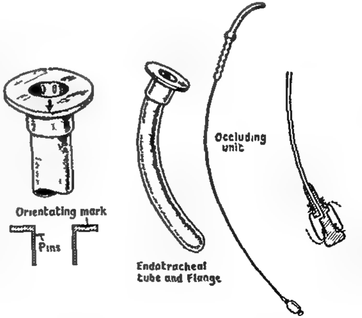
The cuff was fitted to a Magill endotracheal tube in which several large holes were cut under the cuff The tube was specially designed to be used with the Oxford Vaporizer When the concertina bag on the latter instrument was compressed pressure in the tube rose sharply and the cuff if of thin enough rubber inflated and occluded the space between tube and trachea During expiration the cuff deflated

Fig 176 Wilms's Self inflating Cuff (1904)[74]

This was used on endotracheal tubes for experiments on dogs The action of the cuff was similar to that of Mushin's This tube was intended for use with continuous positive pressure anaesthesia According to Wilms when a positive pressure of 10 cm H_2O was reached the cuff became inflated and an air tight fit was made with the trachea Should the animal cough the rise in intrapulmonary pressure made the cuff all the more distended and any tendency to dislodgement was prevented

Fig 177 Halton's Bronchial Occluder (1943)

This instrument consisted of two parts an endotracheal tube and flange and an occluding unit Just inside the opening of the flange were two pins and on the upper surface of the flange was a locating arrow indicating the direction of curvature of the tube The occluding unit was made of stainless steel tubing with a balloon at one end and a rack with slots 1 cm apart at the other The occluder was curved like the endotracheal tube The end tracheal tube was first passed in the ordinary way with the arrow pointing to the diseased side The occluding unit was then inserted with its curvature pointing the same way and the rack engaged in the pins at the required distance The balloon was inflated with saline through tubing connected to the rack of the occluder and the tubing clamped The correct placement of the occluder in the bronchus was confirmed by auscultation of the patient's chest



avoiding stimulation of the laryngeal surface of the epiglottis the manoeuvre could be performed at lighter levels of anaesthesia Kuhn in 1905[71] describes *the same method of exposing the larynx, calling it the 'Reichert principle'*

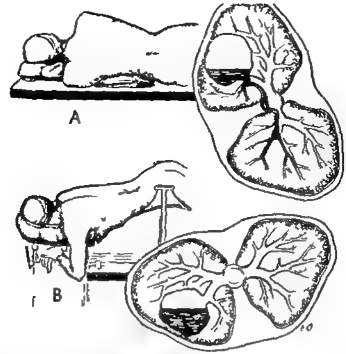


FIG 173 OVERHOLT'S POSITION FOR THORACOTOMY[4] (c 1945)

In (A) the patient is in the lateral position and spilling of secretions occurs from the diseased upper lung to the healthy lower In (B) the advocated prone position the secretions are confined to the diseased lung The patient is supported at three points the hips the shoulders and the head with the diseased side and the head slightly dependent

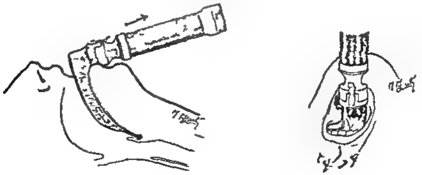


FIG 174 MACINTOSH LARYNGOSCOPE (1943)

1943 Mushin's[7] self inflating cuff (Fig 175) was devised to facilitate controlled respiration with the Oxford vaporizer Though at that time thought to be original, the idea had in fact been used many years before by Wilms[3] for experiments on dogs (Fig 176)

Newton[*] with claws to grip the bronchial wall and so prevent displacement of the balloon (Fig 179)

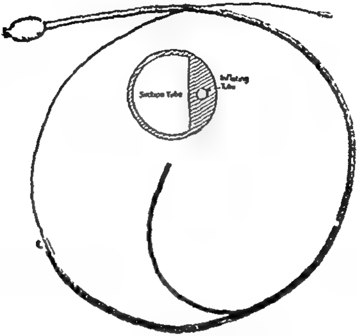


FIG 180 MAGILL BRONCHIAL BLOCKER (1939)[79]
The suction tube and inflating tube are fused together A stilette in the suction tube gives the blocker stiffness to enable it to be placed in position The stilette is then withdrawn The rubber balloon has no cloth covering but in the event of breakage is quickly replaced

FIG 181 RUBBER COVERED SPIRAL WIRE ENDOBRONCHIAL TUBE (RUTH GROVE AND KEOWN 1948)
This tube was passed by means of a bronchoscope inserted through its lumen (Compare this with Magill's tube described thirteen years earlier Fig 164)

1948 The revised and now current blocker (Fig 180) of Magill was introduced

1948 Ruth, Grove and Keown[80] described an endobronchial tube differing only in slight detail from that of Magill published thirteen years earlier (Fig 181)

1943 Two more blockers were devised Halton's[5] (Fig 177), published in 1943, did not become popular, but Thompson's,[6] though never described

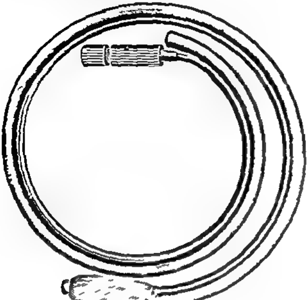


FIG 178 THOMPSON'S BRONCHUS BLOCKER (1943)

This is a robust instrument consisting of two tubes fused together one of which inflates a gauze covered balloon and the other provides drainage or suction from the blocked lung The blocker with its stylet is passed through a full-sized bronchoscope and the cuff inflated. First the bronchoscope and then the stylet is withdrawn

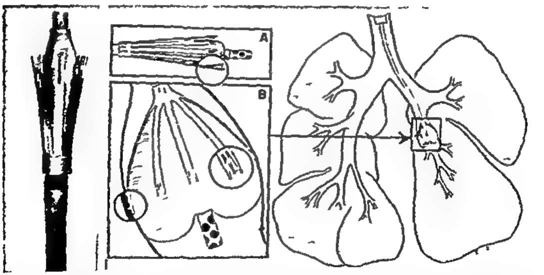


FIG 179 CLAWED BRONCHIAL SUCTION BLOCKER (MOODY TRENT AND NEWTON 1947)

The catheter is made from double lumen Miller Abbott tubing One lumen inflates the distal balloon the other is for suction. Arranged round the balloon is a circlet of thin metal claws the construction of which is shown in (A) When the balloon is inflated the claws are pressed upwards into the bronchial wall (B)

in detail or illustrated except in a catalogue (Fig 178),[7] was taken up all over Britain and is in common use everywhere to-day

1947 A modified bronchial blocker was designed by Moody, Trent and

1950 Bjork and Carlens[41] used their bronchospirometric catheter for anaesthesia (Fig 182) That the use of a beak to locate the catheter on the carina is not new is indicated by the reproduction of Hess's[42] catheter, published in 1912 (Fig 183), which also incorporated this device

1950 The suggestion was made by Mully[43] and later by Stephen[44] that the bronchus to the upper lobe alone should be blocked (Figs 184 and 185) in cases where disease was limited to that lobe

1952 The slot in Albert's bronchoscope[45] represented an old idea put to a new use—anaesthesia It facilitates the removal of the bronchoscope when a blocker has been placed in position (see Fig 137)

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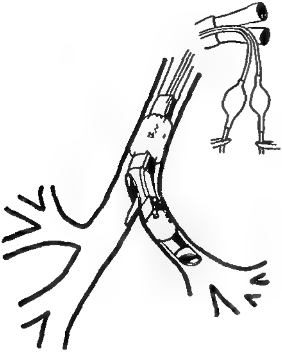

Fig 182

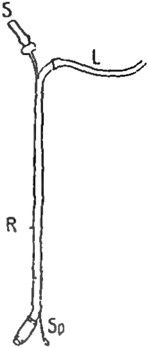

Fig 183

Fig 182 Bjork and Carlens Double Lumen Catheter (1950)

This is a double lumen bronchospirometric catheter with a rubber beak situated just below the tracheal opening The beak hooks on to the carina and is intended to ensure accurate placement in the left main bronchus

Fig 183 Hess's Endobronchial Catheter with Cuff and Locating Spur (1912)

This catheter was devised for experiments on blood gas analysis and was inserted through a tracheotomy opening The catheter was pushed on until the spur hooked over the carina thus locating the tip in the bronchus desired The balloon was inflated with water

S Connection for syringe to inflate cuff Sp Locating spur

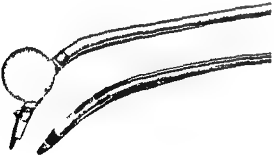

Fig 184 Mully's Upper Lobe Bronchus Blocker (1950)

With this blocker secretions are confined to the upper lobe without interfering with the functioning of the rest of the lung The blocker is inserted under fluoroscopic control it being made of radio opaque rubber for this purpose The curved tip enables the blocker to enter the upper lobe bronchus when the patient's head is extended and flexed to the opposite side

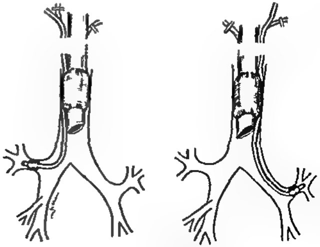

Fig 185 Diagram of Upper Lobe Bronchus Blocker in Position (*ibid*)

CHAPTER XIII

ANAESTHETIC AGENTS CONCLUSION

THE previous chapters have dealt with the main concern of anaesthetists and surgeons during thoracic operations—the maintenance of life while the pleural cavity is open This involves the use of mechanical and other devices to overcome the 'pneumothorax problem' While the choice of particular anaesthetic agents is of more than passing interest, such choice does not affect in any important way the principles whereby the pneumothorax problem is solved For this reason there was no intention as the preface points out, of including descriptions of specific anaesthetic techniques Nevertheless, no book on any aspect of thoracic anaesthesia would be complete without indicating the part played, particularly within the last decade, by the various newer drugs used in this field of anaesthesia

Until the advent of cyclopropane the mainstays of thoracic anaesthesia were ether, chloroform and nitrous oxide either singly or in combination Far sighted suggestions, like those of Brat and Schmieden (p 59) and Janeway (p 78) (Figs 47 and 68), that controlled respiration was the answer to thoracic anaesthesia could not easily be applied with the anaesthetics then available Except perhaps in the case of chloroform, cessation of spontaneous respiration was not easy to produce, and rightly in none of them was such apnoea considered to be either harmless or safe Ether, though believed to be safer than chloroform, was inflammable and explosive, though little information exists about any of these catastrophes occurring Chloroform, though known to be dangerous, remained the anaesthetic of choice for thoracic operations, particularly on the Continent It had great potency, was easy to administer and was not inflammable Because of the respiratory depression and the quiet breathing it inevitably produced, paradoxical movement even during continuous positive pressure anaesthesia was small in amount In addition the general belief was that it was less 'irritant' to the lungs than ether

As the illustrations in Chapter VIII to XI show, there was little lack of ingenuity in developing apparatus for administering nitrous oxide, ether and chloroform in combination with continuous positive pressure or insufflation With the change in emphasis from continuous positive pressure to controlled respiration and from ether and chloroform to relaxants and analgesics, few of these ingenious devices remain in use to day A notable exception is the

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Read also GILLESPIE N A *Endotracheal Anaesthesia* Wisconsin U S A 1946

rotameter (Figs 186 and 187) which had already been adapted for purposes of anaesthesia in 1910[1,2] Its reintroduction in later years enabled the

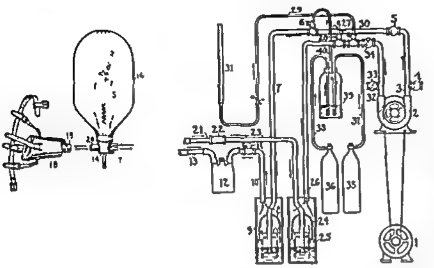


FIG 188 JACKSON'S CARBON DIOXIDE ABSORPTION APPARATUS (1915)

Jackson gives the reason which led him to invent this apparatus

My original object was mainly the production of a method by which nitrous oxide anaesthesia might be made cheaper and safer thereby extending its use particularly to that large and unfortunate proportion of our population which must depend on charity for its surgery

The apparatus consists of a mechanically ventilated reservoir bag from which the patient breathes spontaneously The contents of the reservoir bag are continuously circulated by means of a motor blower through the carbon dioxide absorbent This principle is also made use of in Pinson's apparatus (Fig 87 p 93)

1 Electric motor driving
2 Rotary air pump The gas mixture passes via tubes 3 and 7 to
9 wash bottle containing concentrated solution of sodium hydroxide and calcium hydroxide to absorb carbon dioxide The gases then pass via tube 10 through
12 safety trap to catch any caustic solution and enter
16 reservoir bag from which the patient breathes to and fro via the face mask 18 The gases in the reservoir bag are removed via tube 21 and pass through
25 wash bottle containing concentrated sulphuric acid to remove excess moisture and to sterilize them. They then pass through the rotary blower back to the carbon dioxide absorbent
35 and 36 Cylinders of nitrous oxide and oxygen from which the gases enter the circuit after passing through the washbottle 39 which acts as a simple flow indicator

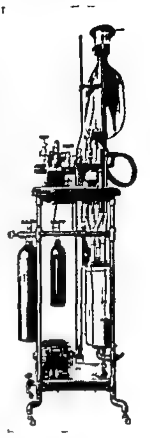


FIG 189

FIG 189 JACKSON'S FIRST EXPERIMENTAL CARBON DIOXIDE ABSORPTION APPARATUS (1915)
The motor and the bottles containing the absorbent solution can be clearly seen

anaesthetist to control more accurately the flows of nitrous oxide and oxygen and helped to play an important part in developing the technique of nitrous oxide anaesthesia

An important development which was to have a far reaching effect was the first perfected carbon dioxide absorber, designed by Jackson in 1915[3] (Figs 188 and 189) Though the idea was not new, it having been mentioned

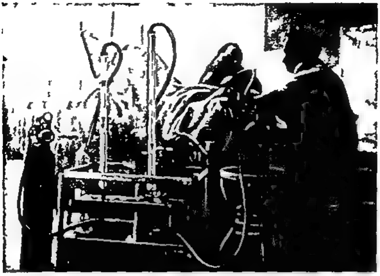


Fig 186

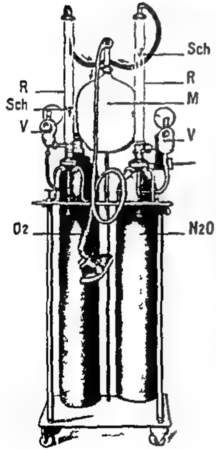


Fig 187

Fig 186 Anaesthetic Rotameters (Neu 1910)

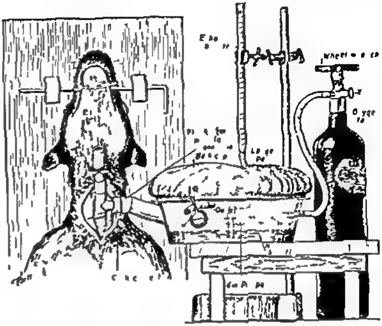
These rotameters made by Rotawerk of Aachen are identical in principle with those of the present day though perhaps a little larger in size It may be that their high cost was the reason for the small interest displayed by the rest of the world in this type of flowmeter for anaesthetic gases for the next twenty years In Germany itself N_2O was not only costly but comparatively scarce and Neu s idea remained undeveloped

Fig 187 The Final Model of Neu s Anaesthetic Apparatus (1911) employing Rotameters for Nitrous Oxide and Oxygen[2]

by Snow,[5] used in mine rescue work by Schwann[6] (Fig 190) and adapted for anaesthesia in a somewhat unphysiological manner by Kuhn (Fig 45,

Fig 192 Jackson's to-and-fro Absorber for Economical Ether Anaesthesia in Animals (1916)

The apparatus was constructed of the homeliest components the main ones being a large cake tin and a rubber bathing cap The carbon dioxide absorbent is caustic soda solution The animal breathes in and out of the cake tin through a wide bore tube the bathing cap acting in place of a reservoir bag Ether is added from the burette while basal oxygen is supplied from the cylinder This method was the direct precursor of the Waters canister and the to-and-fro absorber of to-day



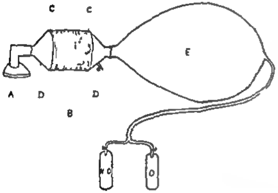


Fig 193 To-and-fro Absorption and the Waters Canister (1924)

This is Waters's original drawing of his absorption system Though described in 1924 it has remained basically unchanged to the present day The entry of fresh gases has now been changed from the bag to near the face mask The stop cock seen attached to the canister was used to obtain gas samples for analysis and was later dispensed with

p 58), Jackson's instrument—particularly his clinical model (Fig 191)—was free from criticism

Soon after designing his first rather complicated apparatus Jackson described[7] a simple method of carbon dioxide absorption for ether anaesthesia in animals which was the direct precursor of the 'to and fro' method of Waters (Fig 192) Waters[8] became interested in Jackson's ideas of economizing in anaesthetic gases, and in 1924 came the invention of the now universally used 'Waters canister (Fig 193)

The clinical use of cyclopropane in 1929[9] in an economical manner was therefore possible It was not long before anaesthetists learnt how easy it was to induce apnoea with cyclopropane and how simple it was to carry out

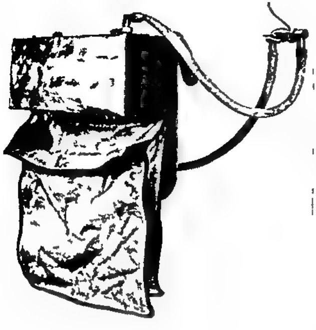


FIG 190. SCHWANN'S CIRCLE CARBON DIOXIDE ABSORPTION MINE RESCUE APPARATUS (1853)

The apparatus which consisted of a large tray of alkali (potassa) for the absorption of CO_2 a reservoir bag and two one way valves was carried on the rescuer's back and connected to the mouthpiece by two wide bore breathing tubes Two small cylinders carried in the pocket supplied the oxygen

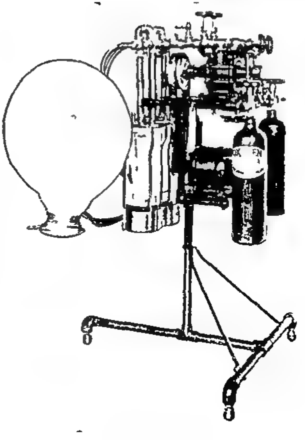


FIG 191 THE IMPROVED CLINICAL MODEL OF JACKSON'S CARBON DIOXIDE ABSORPTION APPARATUS (1916)[4]

The reservoir bag communicated directly with the face mask circulation of the gases from it through the absorbent solutions being maintained by the motor driven blower

use of diathermy, nitrous oxide seemed the obvious anaesthetic to use. However, this gas when used with sufficient oxygen to ensure perfect oxygenation was too weak to be certain that the patient was even unconscious during the operation. To reinforce nitrous oxide, thiopentone was suggested[12] and indeed has a following. However, unless this combination is used with the greatest of caution and the repeated intravenous injections of thiopentone kept to very small doses, a cumulative effect of the barbiturate is possible, leading to a very prolonged recovery.[14, 15]

In the search for a more suitable supplement to nitrous oxide the intermittent intravenous administration of small doses of analgesic drugs has been suggested.[16, 17] The combination of nitrous oxide and an analgesic like pethidine to ensure unconsciousness and freedom from pain, and a relaxant like curare or gallamine (Flaxedil) to maintain apnoea and to obviate reflexes from the thoracic viscera, gives such excellent results both during and after the operation that the technique has been adopted very widely. With the passing of cyclopropane as the main anaesthetic for thoracic surgery in favour of nitrous oxide, economy is no longer the prime reason for the use of an absorber. The absorber still forms an essential part of the anaesthetic equipment because with it comparatively small flows of gas enter the breathing circuit and rhythmic inflation of the lungs is easy. The larger flows of gases which would be needed to ensure adequate carbon dioxide clearance in the absence of an absorber would also mean much tiresome manipulation of spill valves between each inflation.

The future development of thoracic anaesthesia is difficult to forecast. It seems certain that rhythmic inflation of the lungs, whether produced skilfully by hand or under control by an automatic device, will remain the answer to the pneumothorax problem for some time to come.

Although at the moment seemingly hardly within the province of anaesthesia, new developments in the field of cardiac surgery are round the corner, and when the artificial heart and lung, already working well in animals, is applied clinically, a new era of thoracic surgery and anaesthesia will begin. One can envisage the intrathoracic operations of the future being conducted while the heart and lungs are motionless and non-functioning, the maintenance of the circulation, the oxygenation of and the introduction of anaesthetic into the blood being carried on outside the body.

Since we have been mainly concerned in this book with the 'pneumothorax problem' we have made little mention of such important aspects of thoracic anaesthesia as the pre-operative preparation of the patient which makes feasible operations which would otherwise be hopeless undertakings, and the post-operative care without which some, if not many, of the operations of to-day would be followed by a fatal outcome. Nor have we enlarged upon the valuable assistance given by measures like blood transfusion, infiltration

artificial respiration by rhythmically squeezing the bag of the absorber It was but a short step to revert to the older suggestions and to substitute the easily performed and by now well-known manoeuvre of rhythmic inflation of the lungs in an apnoeic patient, for continuous positive pressure as a means of maintaining anaesthesia during thoracotomy

The surgeon was given an operating field characterized by little respiratory movement of the viscera and such as did occur was entirely under the control of the anaesthetist The patient was well oxygenated throughout the operation, carbon dioxide removal was efficient, the circulatory and reflex disturbances were far less than ever experienced before, and at the conclusion of perhaps several hours of anaesthesia the rapid recovery from, and the comparatively few after effects of, the cyclopropane were astonishing The anaesthetist found in cyclopropane an anaesthetic which, with the aid of laryngeal and tracheal cocainization enabled him to perform tracheal or bronchial intubation with ease and speed In the flaccid apnoeic patient, with trachea or bronchus intubated, rhythmic inflation was easy

The practical disadvantages of cyclopropane, however, gradually became apparent It was highly explosive, and a number of explosions with injury and loss of life occurred The most elaborate precautions had to be taken against this accident, from the surgical point of view the most serious outcome was the virtual prohibition of the use of diathermy inside the chest Even this did not prevent explosions[10] and nowadays diathermy is generally banished from the theatre altogether when cyclopropane is used for thoracic operations Another serious disadvantage of cyclopropane was the frequent occurrence of a post operative shock like state which became known colloquially as 'cyclopropane shock'[11] This complication proved worrying and placed a strain on the nursing and medical staff in the immediate post operative period, though the patient generally recovered with little apparent after effects The last disadvantage of cyclopropane was the difficulty of assessing the depth of anaesthesia during the operation Though many helpful suggestions were made in this respect none of them prevented the possibility of overdose of cyclopropane and though such overdose rarely caused the death of the patient it could not be entirely excluded as a causal factor in the production of post operative complications

The introduction of curare into anaesthesia in 1943[1] was, in the case of thoracic anaesthesia, one more instance of the reappearance of a suggestion made long previously (pp 59, 64, and 67) Anaesthetists now had an easy means of inducing apnoea and abolishing reflexes from within the thorax, without the need to use potent anaesthetics Since they were already familiar with controlled respiration with cyclopropane, anaesthetists quickly took up the use of curare as an aid in the production of apnoea

To meet the growing pressure from thoracic surgeons to be allowed the

APPENDIX I

ROUTINE INSTRUCTIONS FOR RESUSCITATION IN FIRST-AID BOXES IN PARIS, 1822[1]

1 Pendant les frictions et l'application des fers a repasser, on se mettra en devoir de retablir le jeu de la respiration, et d introduire de l'air dans les poumons

On se servira a cet effet de la canule courbe en cuivre, qu'on introduira dans l une des narines, en ferment l'autre avec un doigt, on fermera exactement la bouche, pour empecher l air de s echapper par cette cavite

On adoptera a l autre extremite de la canule, le soufflet, qu on fera agir par petites saccades et avec douceur, en evitant d introduire, a chaque mouvement, un trop grand volume d air dans les poumons Entre chaque coup de soufflet il sera bon de presser legerement la poitrine et le bas ventre, de bas en haut et des deux cotes, afin de solliciter l action des poumons L'air qu on introduit dans les poumons doit toujours etre un air pur, c est pourquoi il faut, de preference, employer le soufflet, et ne souffler avec la bouche que lorsqu il est impossible de faire autrement

Il est important de lacher souvent la narine comprimee pour laisser echapper l'air par intervalle, et pour observer si la respiration se retablit

Ordannance concernant les secours a donner aux noyes etc

Prefecture de Police

Paris, le 2 decembre 1822

REFERENCE

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of tissues with vasoconstrictor solutions or the intravenous injection of hypotensives to prevent blood loss, and the use of drugs like procaine and quinidine to minimize cardiac irregularities In connection with each and all of these, active research is in progress and the clinical results of anaesthesia that we regard to day as strikingly good may yet show up poorly when compared with the results of anaesthetic techniques of years to come

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CULLEN, William,[5] 1710–1790 Scottish physician, obtaining his M D, Glasgow, in 1740 He succeeded Johnstone there as Professor of Medicine in 1751 In 1755 he transferred to Edinburgh as Professor of Chemistry, and in 1766 became Professor of the Institute on Theory of Medicine (Physiology) When sixty three years old, he became Professor of Medicine Cullen had a great reputation as a teacher and wrote several books on materia medica and medicine One of his pupils at Glasgow and his successor as Professor of Chemistry at Edinburgh was Joseph Black, a pioneer in scientific chemistry and in the discovery of the true nature of carbon dioxide

CURRY, James[6] Born in Ireland and qualifying in Edinburgh in 1784 he worked as a physician first in Northampton and later at Guy s Hospital in London His *Observations on Apparent Death from Drowning Hanging, etc*, appeared first in 1798 and as a second edition in 1815

DEPAUL Anne Jean Henri[7] 1811–1883 Parisian obstetrician and gynaecologist Born in the Pyrenees of a local legal family, and an orphan by the age of twelve, he decided to study medicine against the wishes of his family With his allowance stopped he ran away from home and studied medicine in Paris while earning his living as a shop assistant After qualifying in 1839 he became interested in obstetrics and ultimately became Professor of Obstetrics in Paris in 1861 He contributed important books and papers to the literature on obstetrics but his fiery nature made him a poor debater Conservative by nature Depaul rejected the use of anaesthetics for natural labour In addition to his medical work he took a lively interest in local government, being a councillor of his commune of the municipality of Paris and later of the Department of Basses Pyrenees

APPENDIX II

BIOGRAPHICAL NOTES

BOUCHUT Jean Antoine Eugene[1] 1818–1891 French physician Born and qualifying in Paris he developed an interest in respiratory disease in children, out of which arose his invention of tubes for insertion into the larynx in the treatment of respiratory obstruction in diphtheritic croup He was appointed Physician at the Children's Hospital in Paris and advanced knowledge in practically all branches of paediatrics His name is also given to a particular type of gasping respiration seen in children with bronchopneumonia

BRAUER, Ludolph[2] 1865–1951 Son of a West Prussian landowner German chest physician and a leading pioneer in the early surgical treatment of pulmonary tuberculosis The operation of thoracoplasty owes its inception to Brauer, who himself suffered from tuberculosis He was an inspiring and enthusiastic teacher and did much for the prestige of German medicine, particularly abroad in South America during the years between the two World Wars He held the Chair of Medicine at Marburg but left to become the Director of the well known Eppendorfer Hospital at Hamburg where he organized medical teaching and created a research institute

CHAUSSIER François[4] 1746–1828 Parisian physician and obstetrician Born at Dijon and starting his medical practice at Besançon, he qualified after studying in Paris He was already locally well known when in 1794 he was asked to organize a school of medicine at Dijon Here he held the Chair of Anatomy and Physiology and acquired his lifelong reputation of being a brilliant teacher and savant Without writing as many papers as was the custom in those days in men of his standing, there were few aspects of medicine to which he did not contribute These included forensic medicine, horticulture and veterinary medicine As Physician to the Maternite his interest centred for a time on ante and neo natal problems of the foetus Chaussier was noted for the Quaker like severity of his dress and mode of life

qualified in medicine, and his diary gives a vivid account of seventeenth century medicine with all its nauseous and horrible pharmacopoea Hooke devoted much attention to the design of air pumps and their use in artificial respiration, but his temperament was not suited to animal experiments and it was left to others to carry on his pioneer work

JACKSON, Chevalier,[1] American endoscopist Born 1865 in Pittsburgh of mixed Yorkshire, French and American stock At the age of four he was already working with tools on wood and early in life became an expert wood turner, carver and inlay craftsman After a hard life as a boy he worked his way through college and medical school as a china and glass decorator, qualifying in 1886 from Jefferson Medical College, Philadelphia After a visit to London to study laryngology he settled in Pittsburgh as a specialist in ear nose and throat surgery From this time on his reputation grew steadily and honours were given him by every part of the world Apart from the tremendous advances which he made in the practice of bronchoscopy and oesophagoscopy he was noted for the great kindness and consideration which he showed his assistants Even after honour and security were his he still had to battle against physical difficulties for he developed pulmonary tuberculosis which forced him periodically to retire from clinical work Characteristically he utilized these periods for writing and study, producing for example his book *Peroral endoscopy and Laryngeal surgery*, during one of these periods Perhaps the achievement which gave him most pleasure was the success he obtained after more than twenty years of lobbying in the face of strong opposition in getting the Federal Caustic Act passed, which compelled the labelling of caustic household cleaners like lye Poison By this he hoped that the numerous cases of oesophageal stricture in children as a result of accidental ingestion would be prevented Jackson is a great man in every way and anaesthetists have reason to remember with gratitude the enormous impetus which Jackson gave to the development and spread of the art of endoscopy and intubation

JANEWAY Henry Harrington 1873–1921 Born in New Brunswick, New Jersey, he qualified in medicine from the College of Physicians and Surgeons, Columbia University, New York in 1898 He became head of the laboratory of experimental surgery at Columbia and Professor of Physiology in the New York Dental School At the same time he became chief of the radium department of the Memorial Hospital Although his contributions to thoracic anaesthesia and to the pathology of shock were great, he is mainly known for his pioneer work in radium therapy He was both an expert radium physicist and a skilled surgeon and laid the foundations of present day radiotherapy

Elsberg, Charles Albert,[8] 1871–1948 General and neurological surgeon, New York Elsberg qualified in 1893 at Columbia University After a brief period of study under von Mikulicz and a few years as general surgeon, he turned his interest to neurological surgery, founding the Neurological Institute of New York It was during his early days when his interests were wide that he developed a machine for endotracheal insufflation anaesthesia His later writings were almost exclusively neurosurgical

Fell, Edward George,[9] 1850–1918 Surgeon and inventor of Buffalo, U S A He was Professor of Physiology and Microscopy at Niagara University from 1885–1895 and though he retained his interest in microscopy he settled down in Buffalo as an ear nose and throat surgeon Besides his interest and inventions in the field of resuscitation, he also invented the first electric chair for executing criminals in 1890, and later a diving apparatus to enable a person to remain under water for a period of time

Hawes, William[10] 1736–1812 A physician practising in Thames Street in London who became the medical attendant of Oliver Goldsmith Perhaps the frequency with which he saw the bodies of drowned people brought out of the Thames made him interested in resuscitation In 1774 with thirty-two other kindred spirits, he founded the Humane Society The list of original founders included Oliver Goldsmith, David Garrick and John Hunter Hawes continued as the leading spirit of the society until his death

He lectured on resuscitation wherever he could find a platform, he petitioned Parliament to erect receiving houses for the drowned or suffocated in every parish in England and to establish schools where medical students might be taught the method of their recovery [8]

Hooke, Robert,[11] 1635–1703 Born at Freshwater, Isle of Wight While at Christ Church College, Oxford he met and worked with Robert Boyle who introduced him to the Royal Society of which he was made Curator of Experiments in 1662, and remained so until he died Hooke was a prolific worker, and carried out a great amount of research work at the Royal Society during his forty years connection with it His inventions, of which there were over one hundred varied from a watch balance spring still used to day to the universal joint still used in transmission gear Hooke eventually

qualified in medicine, and his diary gives a vivid account of seventeenth-century medicine with all its nauseous and horrible pharmacopoea Hooke devoted much attention to the design of air pumps and their use in artificial respiration, but his temperament was not suited to animal experiments and it was left to others to carry on his pioneer work

JACKSON, Chevalier[12] American endoscopist Born 1865 in Pittsburgh of mixed Yorkshire French and American stock At the age of four he was already working with tools on wood and early in life became an expert wood turner, carver and inlay craftsman After a hard life as a boy he worked his way through college and medical school as a china and glass decorator, qualifying in 1886 from Jefferson Medical College, Philadelphia After a visit to London to study laryngology he settled in Pittsburgh as a specialist in ear, nose and throat surgery From this time on his reputation grew steadily and honours were given him by every part of the world Apart from the tremendous advances which he made in the practice of bronchoscopy and oesophagoscopy he was noted for the great kindness and consideration which he showed his assistants Even after honour and security were his he still had to battle against physical difficulties for he developed pulmonary tuberculosis which forced him periodically to retire from clinical work Characteristically he utilized these periods for writing and study, producing for example, his book *Peroral endoscopy and Laryngeal surgery*, during one of these periods Perhaps the achievement which gave him most pleasure was the success he obtained, after more than twenty years of lobbying in the face of strong opposition in getting the Federal Caustic Act passed which compelled the labelling of caustic household cleaners like lye Poison By this he hoped that the numerous cases of oesophageal stricture in children as a result of accidental ingestion would be prevented Jackson is a great man in every way and anaesthetists have reason to remember with gratitude the enormous impetus which Jackson gave to the development and spread of the art of endoscopy and intubation

JANEWAY Henry Harrington[13] 1873–1921 Born in New Brunswick New Jersey, he qualified in medicine from the College of Physicians and Surgeons Columbia University New York in 1898 He became head of the laboratory of experimental surgery at Columbia and Professor of Physiology in the New York Dental School At the same time he became chief of the radium department of the Memorial Hospital Although his contributions to thoracic anaesthesia and to the pathology of shock were great he is mainly known for his pioneer work in radium therapy He was both an expert radium physicist and a skilled surgeon and laid the foundations of present-day radiotherapy

KILLIAN, Gustav,[14] 1860–1921 Professor of Laryngology, Berlin Though not one of the founders, Killian was largely responsible for the development of laryngology into the specialty it is to day In addition to his contribution to the general technique of ear, nose and throat surgery (at least two operations bear his name), he had a particular interest in advancing the practice of bronchoscopy and oesophagoscopy He is reputed to have been the first to remove a foreign body from the bronchus by this means Of his many literary works he is best known for his books on the nasal cavities, on oesophagoscopy and bronchoscopy and on suspension laryngoscopy

KIRSTEIN, Alfred,[1] born 1863 German physician of Berlin In 1895 he invented the method of direct examination of the larynx and trachea without using mirrors, which he called 'autoscopy For this purpose he designed the first self illuminated endoscope by adding a suitable spatula to Caspar's hand lamp

KITE, Charles,[15] died 1811 A member of the Corporation of Surgeons in London, practising at Gravesend throughout his life He was a prolific writer, and included among the diverse topics on which he wrote were two essays, one in 1788, 'An Essay on the Recovery of the Apparently Dead,' and the other in 1795, 'Essays and Observations Physiological and Medical on the Submersion of animals etc The former essay was successfully submitted in competition for the silver medal offered by the Humane Society for the best contributions on the subject of resuscitation from drowning

KUHN Franz[16] 1866–1929 Qualifying in 1891 in Wurzburg he ultimately became the Director of the St Norbert Hospital in Berlin Schoneburg His main work was *Die perorale intubation* published in 1911 He was a great pioneer of endotracheal intubation particularly by the blind tactile method Working as he did in a country in which regard for anaesthesia was at a low level, it was little wonder that his enthusiastic advocacy of intubation met with such little encouragement

LEROY D ETOILLES, Jean Jacques Joseph[17] Born in 1798 in Paris of an old military family Though of wide surgical interests he is chiefly remembered for his interest in stone in the bladder and its treatment by the lithotrite and for his condemnation of the use of bellows for resuscitation He gives his name to an assortment of instruments including a lithotrite, a tonsil guillotine and a uterine speculum He did not limit his activities to medicine for he was also the inventor of a machine gun bullet, a shell which would burst on impact and a rifled breech loading cannon

MATAS, Rudolph.[18] Born in 1860 in Louisiana of Spanish parents he qualified from the University of Louisiana (now Tulane) in 1880 and after an internship at the Charity Hospital, New Orleans, was made Chief of Clinic there. From 1894 till his retirement in 1927 he was Professor of Surgery in New Orleans. His contributions to surgery were many and far reaching and only a few of the subjects in which he was a pioneer can be mentioned. These included aseptic surgery, spinal anaesthesia, the advocacy in 1888 of continued intravenous drip for shock and haemorrhage and in 1911 of continuous gastro-duodenal suction for intestinal obstruction, intrathoracic surgery and the surgery of aneurysms and other blood vessels. His numerous papers are characterized by their pungency of vocabulary and clarity of expression.

MELTZER, Samuel James,[19] 1851–1920. Born in N.W. Russia young Meltzer seemed destined at the age of sixteen to become an eminent member of the Rabbinate. He proved a disappointment to his parents by running away from home. By 1882 he had qualified in medicine but refused to stay in Germany where the positions offered to him were conditional on baptism. Arriving in the United States in 1883, he settled down in practice in New York, but soon abandoned this to become head of the Department of Physiology and Pharmacology of the Rockefeller Institute in 1907. His scientific career was a distinguished one and he received academic honour from many universities, including that of St Andrews. He made contributions to practically every aspect of physiology, particularly those which had direct clinical interest. His laboratory fostered romance, for his daughter Clara, who was also his assistant, married John Auer, another of his assistants, with whom he published the now famous insufflation experiments described on page 67.

MEYER, Willy,[20] 1858–1932. Born at Minden, Germany, he graduated at Bonn. He worked under Trendelenburg at Leipzig for three years and then emigrated to America in 1884, settling in New York City. He was the first to perform ureteric catheterization. Meyer was a prodigious writer, indicated by the fact that to one journal alone between 1884 and 1924 he made 357 contributions. It was in his later years that he became interested in thoracic surgery and wrote numerous articles on every aspect of the subject. He was one of the founders of the American Association of Thoracic Surgery, whose first president was S. J. Meltzer.

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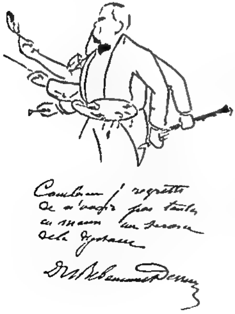
PARACELSUS[22] (the name by which Phillipus Aureolus Theophrastus Bombastus von Hohenheim became known), 1490–1541. Born in Switzerland near Zurich. Starting as a chemist in a lead mine laboratory, he learnt medicine both in his father's practice and during his extensive wanderings all over Europe. On his return to Switzerland in 1526, he was appointed town physician in Basle and lecturer in medicine at the university. Here he was something of a disturbing influence and caused commotion not only by lecturing in German instead of Latin, but by his condemnation of Galen, whose works he publically burnt on one occasion. He was soon forced to take to the road once more, dying in Salzburg in 1541. He goes down in history as a turbulent spirit, upsetting the then firmly established reputation (almost dogma) of Galen and the ancients, and for starting off what later became known as the renaissance in medicine.

PUGH, Benjamin,[22] c. 1750. A surgeon of Chelmsford, Essex, with a very strong interest in obstetrics. His *Treatise of Midwifery* was based on over 2,000 cases of his own. In this book he describes his invention of the flexible 'air pipe' which he used in new born babies with respiratory difficulty, born after delay in the delivery of the after coming head. Many other novel instruments are described in his book, including obstetric forceps having for the first time, the pelvic curve of which he is regarded by some as the originator in preference to Smellie.



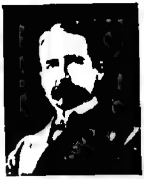
RIBEMONT-Dessaignes, Alban Alphonse Ambroise.[14] Born in 1847 in Vendome, France. Qualifying in 1878 in Paris, he took up obstetrics finally reaching the post of Professor of Obstetrics in Paris. Amongst his many contributions to his subject were papers on resuscitation of the new born in which intubation of the trachea with a tube of his own design was described. Ribemont's diversity of interest is indicated by the cartoon.

MONRO, Alexander[5] (secundus), 1733–1817 The second of the three Monros (father, son and grandson) who held the post of Professor of Anatomy at Edinburgh continuously from 1720 to 1846 He proved, in fact, to be a greater and more brilliant man than his father, making many contributions to anatomical knowledge The foramen of Monro in the brain is named after him Monro developed the method of demonstrating live animal preparations, the animals being kept alive, after the removal of the chest wall by inflation with bellows When the tongue fell back and obstructed the larynx Monro had overcome such obstructions by passing a catheter into the larynx by way of the mouth '[10] In 1776 Dr Wm Cullen Professor of Physics at Edinburgh, recommended the use of Monro s bellows in resuscitation of the drowned in a pamphlet, A letter to Lord Cathcart,' Edinburgh, 1776 (Cathcart was President of the Board of Police in Scotland)

In 1798 Monro, who had himself become professor at the age of twenty two, asked the Town Council of Edinburgh to appoint as his colleague and successor his eldest son Alexander then twenty five After some demur the Council agreed, and the two Monros held the Chair jointly for ten years until the elder retired in 1808 Monro the third held the Chair until 1846—thus the family had held the Chair for 126 years

O DWYER Joseph[21] 1841–1898 Born in Cleveland Ohio, he was brought up near London Ontario He returned to New York for his medical studies graduating in 1866 His interest in intubation was started by a bad epidemic of diphtheria in 1872 and he saw over 400 of the child sufferers doomed to the horrors of asphyxiation with doctors helpless to do any thing He applied himself to the problem of saving these children inventing tube after tube although his work was not recorded until a history of the Foundling Hospital was written in 1884 His method of intubation was not well received by his contemporaries and O Dwyer did not receive the credit he deserved until long after his death A colleague Dr Northrup, speaking of O Dwyer, said

> In the maternity service he was the expert obstetrician in intubation an inventor and teacher, in general medical service the constant consulting mind whose opinion in times of clinical difficulties *and troubles everyone sought*



TUFFIER, Theodore,[16] 1857–1929. Born at Bellême in France he qualified in Paris in 1879 becoming surgeon to three important hospitals in Paris. Tuffier had an international reputation and was one of the first exponents of experimental surgery. He was a pioneer in the operative treatment of diseases of the kidneys, of fractures and of diseases of the lung. He also made important contributions to the knowledge of spinal anaesthesia. His major publications include those on surgery of the kidney, on surgery of the lung, on spinal anaesthesia and on surgery of the stomach.

VESALIUS, Andreas,[27] 1514–1564. He was born in Brussels of a family celebrated for the number of its eminent medical men. While still almost a schoolboy at Louvain, he developed a passion for anatomy, dissecting rats, dogs and other animals. Human anatomy at this period was scarcely a science; the practice of dissection was regarded as unlawful and impious, the teaching of the Schools was looked upon as sacred, and no one dared question the validity of the ancient doctrines. In this atmosphere it is striking that advances in anatomical knowledge were made and these were solely attributable to the exertions of Vesalius. His work, *De Humani Corporis Fabrica*, was written at an early age, and is now an anatomical classic work. Vesalius served as an army surgeon for a few years, then in 1537 he became Professor of Anatomy at Padua. He attacked the works of Galen consistently and for this he was bitterly persecuted, nevertheless, the Galenists were compelled to dissect the human body in order to refute the arguments of Vesalius. His portrait was painted by Titian who also drew many of the illustrations in his book.

VOLHARD, Franz,[16] 1872–1950. German physician. Born in Munich and qualifying at Halle in 1897, Volhard worked at various German centres before becoming Professor of Medicine first at Halle in 1918 and then at Frankfort on Main in 1927. His interests and publications were mainly on diseases of the stomach (he discovered lypase in 1899), heart and kidneys. His name is given to the Volhard 'fat breakfast' and to the Volhard water test for kidney function. Among his publications were three important books on Bright's Disease of the Kidney.

Sauerbruch, Ferdinand,[16 21] 1875–1951 Born in Barmen, Germany qualified at Leipzig in 1902 For the next ten years he worked with such distinguished and stimulating men as Langerhans, von Mikulicz, and Friedrich He became Professor of Surgery in Marburg 1907, in Zurich, 1911, in Munich, 1918, and in Berlin, 1927 In 1893 Sauerbruch was set the problem of the pneumothorax syndrome, and his solution—differential pressure breathing—remained the guiding principle for thoracic surgeons until the outbreak of World War II Sauerbruch though Prussian in his manner and methods, was a great pioneer of thoracic surgery, and it must be a source of admiration that he accomplished so much without the assistance of expert anaesthetists and all that they mean to the thoracic surgeon of to day

Snow, John,[25] 1813–1858 Of Yorkshire farming stock His first interest was in general medicine and particularly its preventive aspects At the age of fourteen while an apprentice to a surgeon at Newcastle he saw a cholera epidemic in full force In 1848 stimulated perhaps by this early experience, he determined how cholera was spread His paper in 1849 on the Mode of Communication of Cholera was to be confirmed during the cholera outbreak in London in 1854 when Snow showed the focus of spread to have been the Broad Street pump Between 1841–1843 several papers on asphyxia and the circulation were written He took up the study of anaesthetics in 1846 and before his death in 1858 he had written two important books, *The Inhalation of Ether* (1847) and *On Chloroform and other Anaesthetics* (1858) By administering chloroform to Queen Victoria he stilled much clerical criticism of anaesthesia in labour During the twelve years that Snow devoted to anaesthesia he carried out an astonishing amount of original research and laid the foundation for the scientific and experimental approach to anaesthesia

Trendelenburg Friedrich[26] 1844–1924 German surgeon Although qualifying at Berlin he started his medical training at Glasgow He became Professor of Surgery at Rostock Bonn and Leipzig and was one of the great men of German surgery, making contributions to almost every field of the art Among his many proteges was Willy Meyer the inventor of the cabinet *on page 54 and Wilms (q v) He left his name attached not* only to a tracheal tube and cuff but to his famous position, certain tests (for example, for varicose veins) and to the dramatic operation for the removal of a pulmonary embolus

INDEX

Ab orption anae thesia (see Carbon dioxide absorption)
Acapnia in controlled respiration 18
Adelman M H et al on Burns Pressure Balance Resuscitator 100
Adhesion pleural Matas on 44
  to prevent pneumothorax syndrome 1
  Quenu and Longuet on 47
Adrenalin-saline drip Meyer's use of 65
  Evan s use of 65
Aga Stille closed circuit circle absorber on 93
Air fixed and phlogisticated effect on respiration 39
Albert S N slotted bronchoscope 120 141
Anaesthesia assessment of depth in controlled respiration 21
  in labour criticism of stopped by Snow 160
  surface and Coryllos-McKesson tube 129
  surface and Zavod s bronchospirometric catheter 130
  thoracic future development of 149
Anaesthetic agents and thoracic anaesthesia 143
Anderson E, Crafoord C, and Frenckner P on Spiropulsator commercial model 90 91
Annandale J endotracheal tube 112
Apnoea after inflation with oxygen 49
  and one lung anaesthesia Rovenstine 132
  Green s use of in experimental surgery 78
  Green and Janeway s apparatus 78
  hyperventilation 18
  and Frenckner s Spiropulsator 90 91
  produced by curare 59 148
  reflex 18
  with insufflation anaesthesia 68
Apparatus automatic for controlled respiration (see Respiration controlled)
Archibald E control of secretions by bronchus blocker 130
Aspiration of blood etc prevention of
  by bronchus blocker 130–140
  by endobronchial tube 128 132 133 139 140
  by posture Beecher 135 Overholt 136
  by suction 14 122 129
  by Trendelenburg tube with cuff 109
Assisted respiration (see Respiration assisted)
Atelectasis pressure fluctuation in 25
Auer J (see Meltzer and 67 137)
Autoscope Kirstein s 114

Bailey H and Bishop W J *Notable Names in Medicine and Surgery* 160 162
Barthelemy and Dufour insufflation apparatus 69
Bazy thoracotomy opening plugged by fingers 1
Beecher H K control of secretions by posture 135
Bellows advocated by Cullen 31
  Alexander Munro s 31
  Fell s 44
  Fell O Dwyer 45
  for inflation of lungs 29
  instruction for use of Paris 151
  John Hunter s 31
  Leroy s Safety 36
Bellows—*continued*
  Royal Humane Society s 31 107
  (see also Resuscitation apparatus for)
Bennett Resuscitator 100
Bible The mouth-to-mouth artificial respiration 28
Bjork V O and Carlens E double lumen endobronchial tube 140
Blache Nelaton and Trousseau condemn Bouchut s intubation method 43
Black J discovers carbon dioxide 153
Blease Pulmoflator (1936) pattern 97
  (1950) pattern 98
  mode of action 98–99
Blocker bronchial Albert s slotted bronchoscope for 120
  Archibald controls secretions with 130
  Griffiths suggests 131
  Halton s 137
  Magill s 133
  Magill s modified 133
  Magill s (1939) 139
  Moody et al s clawed 138
  Mully s for upper lobe bronchus 140
  Stephen s for upper lobe 141
  Thompson s 138
Blocker gullet for resuscitation
  Coleman s 106
  Curry s 105 106
Boothby W M insufflation anaesthesia with nitrous oxide 70
Bouchut attempts intubation for croup 43 108
  biography 152
  Bouchut respiration 152
  intubation method condemned by Trousseau 43
  work on paediatrics 152
Boyle s apparatus Williams automatic breathing attachment for 101
Bozzini P Endoscope 107 108
Brat and Schmieden positive pressure apparatus 59
  suggest controlled respiration 143
  suggest use of curare 59
Brauer L biography 152
  on disadvantages of water valves 54
  pendelluft 6
  positive and negative pressure methods 52 53
  positive pressure method 52
  work on pulmonary tuberculosis and thoracoplasty 152
  Über Pneumothorax 6
Brodie B B on thiopentone cumulative effect of 149
Bronchiectasis secretions controlled by bronchus blocker 130
Bronchoscope Albert s slotted pattern 120 141
  Brunning s extension used by Magill 133
  Frenckner s double for bronchospirometry 130
  Frenckner s for inserting endobronchial tubes 131
  Killian s 115
  Magill s for inserting endobronchial tubes 132
Bronchospirometry Frenckner s double bronchoscope for 130

Wilms, Max,[6] 1867–1918 German surgeon As assistant to Trendelenburg at Leipzig he acquired a reputation as a pathologist, publishing a book on growths of the kidney, one of which is known to this day as Wilms tumour He became Professor of Surgery at Basle and Heidelburg Wilms was very interested in thoracic surgery and modified the operation of thoracoplasty which had been suggested by Brauer

Woillez, E J,[16, 29, 30] 1811–1882 The son of Natalie Woillez, the famous French novelist He was a physician of the Charite in Paris, and a member of the French Academy of Medicine His main interest was in respiratory disease, about which he wrote several papers The Spirophore, for which he is principally remembered was invented in 1876 but in spite of pressure from his instrument maker Woillez refused to patent his invention The apparatus won a silver medal in an exhibition of life-saving apparatus held at Le Havre

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INDEX

Absorption anaesthesia (see Carbon dioxide absorption)
Acapnia in controlled respiration 18
Adelman M H, [illegible] on Burn Pressure Balance Resuscitator 100
Adhesion pleural Matas on 44
to prevent pneumothorax syndrome 1
Quenu and Longuet on 47
Adrenalin-saline drip Meyer's use of 63
Ivan's use of 63
Aga Stille closed circuit circle absorber 90 93
Air fixed and phlogisticated effect on respiration 30
Albert S N slotted bronchoscope 120 141
Anaesthesia assessment of depth in controlled respiration, 21
in labour criticism of stopped by Snow 160
surface and Cornillon-McKesson tube 129
surface and Zavod's bronchospirometric catheter 130
thoracic future development of 149
Anaesthetic agents and thoracic anaesthesia 143
Anderson E Crafoord C and Frenckner P on Spiropulsator commercial model 90 91
Annandale J endotracheal tube 112
Apnoea after inflation with oxygen 30
and one lung anaesthesia Rovenstine 132
Green's use of in experimental surgery 78
Green and Janeway's apparatus 78
hyperventilation 18
and Frenckner's Spiropulsator 90 91
produced by curare 59 148
reflex 18
with insufflation anaesthesia 68
Apparatus automatic for controlled respiration (see Respiration controlled)
Archibald E control of secretions by bronchus blocker 130
Aspiration of blood etc prevention of
by bronchus blocker 130–140
by endobronchial tube 128 132 133 139 140
by posture Beecher 135 Overholt 136
by suction 14 122 129
by Trendelenburg tube with cuff 109
Assisted respiration (see Respiration assisted)
Atelectasis pressure fluctuation in 23
Auer J (see Meltzer and 67 157)
Autoscope Kirstein's 114

Bailey H and Bishop W J *Notable Names in Medicine and Surgery* 160 162
Barthelemy and Dufour insufflation apparatus 69
Bazy thoracotomy opening plugged by fingers 1
Beecher H K control of secretions by posture 135
Bellows advocated by Cullen 31
Alexander Munro's 31
Fell's 44
Fell-O'Dwyer 45
for inflation of lungs 29
instruction for use of Paris 151
John Hunter's 31
Leroy's Safety 36
Bellows—*continued*
Royal Humane Society's 32 107
(see also Resuscitation apparatus for)
Bennett Resuscitator 100
Bible The mouth to-mouth artificial respiration 28
Björk V O and Carlens E double lumen endobronchial tube 140
Blache Nelaton and Trousseau condemn Bouchut's intubation method 43
Black J discovers carbon dioxide 153
Blease Pulmoflator (1946) pattern 97
(1950) pattern 98
mode of action 98–99
Blocker bronchial Albert's slotted bronchoscope for 120
Archibald controls secretions with 130
Griffiths suggests 131
Halton's 137
Magill's 133
Magill's modified 133
Magill's (1930) 139
Moody et al's clawed 138
Mully's for upper lobe bronchus 140
Stephen's for upper lobe 141
Thompson's 138
Blocker gullet for resuscitation
Coleman's 106
Curry's 105 106
Boothby W M insufflation anaesthesia with nitrous oxide 79
Bouchut attempts intubation for croup 43 108
biography 152
Bouchut respiration 152
intubation method condemned by Trousseau 43
work on paediatrics 152
Boyle's apparatus Williams automatic breathing attachment for 101
Bozzini P Endoscope 107 108
Brat and Schmieden positive pressure apparatus 59
suggest controlled respiration 143
suggest use of curare 59
Brauer L biography 152
on disadvantages of water valves 54
pendelluft 6
positive and negative pressure methods 52 53
positive pressure method 52
work on pulmonary tuberculosis and thoracoplasty 152
Über Pneumothorax 8
Brodie B B on thiopentone cumulative effect of 149
Bronchiectasis secretions controlled by bronchus blocker 130
Bronchoscope Albert's slotted pattern 120 141
Brunning's extension used by Magill 133
Frenckner's double for bronchospirometry 130
Frenckner's for inserting endobronchial tubes 131
Killian's 115
Magill's for inserting endobronchial tubes 132
Bronchospirometry Frenckner's double bronchoscope for 130

Bronchus tamponade of for control of secretions
Crafoord 135
Brunning bronchoscope extension used by Magill 133
Brunton J aural endoscope 110
Bunnell S loaded expiratory valve for positive pressure anaesthesia 62
preferred to rhythmic inflation 83
Burns H I Pressure Balance Resuscitator 99
Burstein C L on apnoea 18

Cannula François Franck s used by Tuffier 46
(see also Tube endotracheal)
Cap s intubating tube and pump 31
Carbon dioxide discovered by Black 153
level in blood effect of controlled respiration on 17
removal in insufflation 68
Verworn s experiments with 64
Carbon dioxide absorption apparatus
Aga Stille 90–93
Heidbrinck 93
Kuhn s circle 58
Jackson s 145
Jackson s improved pattern 146
Jackson s to and fro 147
McKesson 94
Pinson s 95
Schwann s mine rescue apparatus with 146
Waters canister 93
Guedel and Waters cuffed tube for 126
Snow s use of 147
Use with nitrous oxide anaesthesia 149
Carbon dioxide accumulation during insufflation anaesthesia
prevention of [redacted] 70 76
Volhard s experiments on 70
during positive pressure anaesthesia 64
in Brauer s apparatus 53
Comroe and Dripps on 11
Moyer and Beecher on 11
Cardiac output effect of controlled respiration on 16
effect of paradoxical respiration on 7
effect of positive pressure on 12
Cardiac surgery future methods 149
Carlens E (see Bjork and Carlens) 140
Caspar s hand lamp and Kirstein s Autoscope 156
Cassell W H laryngoscope with curved blade 123
Chaussier F biography 152
oxygen therapy apparatus 40
resuscitation of the newly born 39
bag and mask for 39
cannula for 41 106
experience with household bellows for 39
Chauvel biography of Depaul 153
Chest anaesthesia early methods 44
Chloroform apparatus for
Alcock s (Morriston Davies) 63
Drager 51 52 56–58 63
Trendelenburg s cone 109 114 118
Vernon Harcourt s 69
choice of for chest operations 143
paradoxical respiration reduced by 143
used by Brat and Schmieden 59
Doyen 114
Kuhn 56–58 118
Maydl 113
Quenu and Longuet 47
Snow 45
Tiegel 60 61

Cholera Snow on 160
Circulation effect of opening chest on 49
Closure of chest wall 23
Cogan T handbook on resuscitation 31
Coleman s gullet blocker 106
Comrie J D *History of Scottish Medicine to 1860* 153 158
Comroe J H and Dripps R [redacted] on carbon dioxide accumulation 11
Controlled respiration (see Respiration controlled)
Coryllos McKesson endotracheal tube 129
Cotton F J insufflation anaesthesia with nitrous oxide 79
Coughing effect on paradoxical movement 7 8
pressure produced by 15
Cough reflex clearance of secretions by 8 14
in chest surgery with spinal anaesthesia 14
Cournand A et al on expiratory pause with rhythmic inflation 17
Courtois Hans resuscitation pump 31
Crafoord C bronchial tamponade for control of secretions 135
indirect vision endotracheal tube introducer 48 134
modification of Frenckner s Spiropulsator 89
on difficulties of intubation 48 135
on disadvantages of original Spiropulsator 90
On the Technique of Pneumonectomy in Man 48
Croup diphtheritic
Bouchut on intubation for 43 108
O Dwyer s tube for 42 43 111
Cuff removable Guedel and Waters 127
Janeway s 79 123
Mushin s [redacted]lf inflating 137
Wilm s self inflating 137
Cullen W biography 153
on inflation of lungs with bellows 31
Curare apnoea produced by 148
Brat and Schmieden suggest use of 59
Meltzer and Auer s use of 67
Nagel s use of 69
reflexes abolished by 149
use in anaesthesia 148
Volhard s use of 64 70
Curry J biography 153
Popular observations on apparent death from drownin 33 104
resuscitation instruments 33 105–106
Cutler E C biography of Matas 157
Cyclopropane apnoea with 147
diathermy and 148
difficulties with 148
disadvantages of 148
explosion with 92 148
in chest anaesthesia 148
Pinson s apparatus for constant suction with 95
replaced by nitrous oxide 149
Shock 148
use with Spiropulsator 90
with Waters canister 147
Cyst of lung dangers of 20

Davies H Morriston endotracheal tube with cuff 63 122
positive pressure apparatus 63

Dead space effect of positive pressure on 11
reduced with insufflation 70
Death in positive pressure anaesthesia 64
Deflation of lung controlled by water valve 46
Depaul A. J. H. biography 153
intubation tube for resuscitation 41 107 108
Dern R. J. and Fenn W. O. effect of positive pressure on venous pressure 12
Desault on intubation for oedema of the glottis 43
Desgranges [illegible] resuscitation pump 31
Desormeaux A. J. *De l'Endoscope et de ses Applications* etc 108
Endoscope 109
the father of endoscopy 108
Diathermy and cyclopropane 148
and nitrous oxide 141
Dibble H. L. use of Pulmotor 83
Diphtheria O'Dwyer's work on [illegible]
Dorrance G. M. apparatus for chest anaesthesia 121
end tracheal tube with cuff 79 121
on Fell-O'Dwyer tube 121
Doyen E. *Technique Chirurgicale* 114
endotracheal tube 114
uses Trendelenburg cone 114
Drager positive pressure apparatus 65
Pulmotor for resuscitation 81
(see also Roth Drager 51–52)
Drugs newer part played by 143
Dripps R. D. Cyclopropane shock 148

Ehrenfried insufflation apparatus 75
Eisenmenger V. endotracheal tube with cuff and pilot balloon 113
E & J Resuscitator 82
Electric chair invented by Fell 154
Elisha's mouth-to-mouth method of resuscitation 28
Elsberg C. A. advocates laryngoscopy for intubation 73
biography 154
first insufflation apparatus 72
portable insufflation apparatus 73 122
Endobronchial tube (see Tube endobronchial)
Endoscope Bozzini's 107 108
Brunton's aural 110
Desormeaux's 109
Kirstein's Autoscope 114 115
Voltolini's 110
(see also Bronchoscope and Laryngoscope)
Endoscopy first successful use by Desormeaux 108
Endotracheal insufflation (see Insufflation)
tube (see Tube endotracheal)
Erichsen J. recommends oxygen for resuscitation 38
resuscitation pump 37
Ether anaesthesia and controlled respiration 143
explosions with 143
in insufflation method
Ehrenfried's apparatus 75
Elsberg's apparatus 72 73
Janeway's apparatus 74
Kelly's apparatus 76
Meltzer and Auer's apparatus 67 68
Robinson's experiments 70
Robinson's apparatus 75
Shipway's apparatus 76

Ether anaesthesia—*continued*
in positive pressure method
Drager apparatus 65
[illegible]'s use of 62
Murphy's use of 53
Tiegel's use of 61
Jackson's to-and-fro absorber for 147
the Flagg can for 126
Evans E. adrenalin-saline drip 65
Expiration passive nature of 14
Explosion and broncho-pleural fistula 10
with cyclopropane 148
with cyclopropane in Spiropulsator 92
with ether 143

Fell G. E. biography 154
invents electric chair 154
resuscitation apparatus O'Dwyer's tube for 111
rhythmic inflation apparatus for artificial respiration 41
Fell-O'Dwyer resuscitation apparatus 41
adapted by Matas 41
Dorrance on disadvantages of 121
use in thoracic surgery 41
Fine's leather intra-laryngeal tube 51
First Aid Boxes 31
instructions for use of [illegible] 151
Fischer I. *Biographisches Lexikon* 154 159 162
Fistula broncho-pleural danger of explosion with 10
flooding of bronchi from 10
Flagg P. J. endotracheal tube and apparatus 126
laryngoscope 128
the Flagg can 126
Flaxedil (Gallamine) reflexes abolished by 149
Fontana experiments on respiration 30
Franck François cannula 46
Frenckner P. *Bronchial and Tracheal Catheterisation* 7
bronchoscope for inserting endobronchial tubes 131
double bronchoscope for bronchospirometry 130
endotracheal tube with cuff 87 129
on positive pressure breathing 86
on the Pulmotor 83
on rhythmic inflation 86
paradoxical respiration effect of position on 7
Spiropulsator 86–91
work with Giertz 86

Gale J. W. and Waters R. M. first endobronchial tube for anaesthesia 128
Gallamine (Flaxedil) reflexes abolished by 149
Garré and Quincke *Grundrisse der Lungenchirurgie* 4
influence of size of thoracotomy opening on pneumothorax syndrome 4
Garrick David member of Humane Society 154
Giertz K. H. Crafoord and Frenckner work with 86
experiments with positive pressure methods 19 86
Gillespie N. A. *Endotracheal Anaesthesia* 143
Glottis oedema of Desault on intubation for 43
MacEwen on intubation for 111
Goldsmith Oliver member of Humane Society 154
Goodwyn E. *The Connexion of Life with Respiration* 33
on Nooth's and other pumps 33
Graham E. A. in *Thoracic Surgery* by H. Lilienthal 4
on surface tension and adhesion of pleura 4

Gray T C on nitrous oxide thiopentone anaesthesia 149
Gray T C and Edwards F R on dangers of lung cysts 20
Green N W endotracheal tube with cuff and pilot balloon 119
rhythmic inflation anaesthesia for experimental surgery 78
Green N W and Janeway H H rhythmic inflation apparatus 60 78
on value of controlled respiration 79
Griffiths H suggests bronchus blocker to Archibald 131
Griffiths H R and Johnson G E introduce curare into anaesthesia 148
Guedel A E and Treweek N controlled respiration in abdominal surgery 14
Guedel A E and Waters R M a new intratracheal catheter 126
removable cuff for 1 7
Gurd F B et al spinal anaesthesia for thoracic surgery 14
poor results of 15
Guthrie D *A History of Medicine* 159
Gwathmey J T insufflation anaesthesia with nitrous oxide 79

Hacker von sword swallowing method of oesophagoscopy 115
Haemorrhage effect of positive pressure anaesthesia on 12
Halton J bronchial occluder 137
Handgrip method Mullers 1
Harcourt Vernon chloroform apparatus 69
Hawes W biography 154
formation of Humane Society 31
Head H endobronchial cannula with cuff 112
Heart artificial 149
Heidbrinck apparatus Mautz automatic device for 93
Henle Professor 60
Hess R endobronchial catheter 140
Hill W slotted laryngoscope 119
slotted oesophagoscope 120
Hirsch A *Biographisches Lexikon* 153
Hirsch A and Hubotter F *Biographisches Lexikon* 162
Hook Robert animal experiments with inflation of lungs 29
biography 154
use of insufflation method 68
Humane Society Royal formation of 31 154
resuscitation instruments 32 107
endotracheal tube 32 107
Hunter John experiments on resuscitation with bellows 31
member of Humane Society 154
Hyperventilation inhibition of respiratory centre by 18

Infection spread of and the Coryllos McKesson tube 129
Inflation rhythmic of the lungs 14
advantages of 21
dangers with cyst of lung 20
during pleural closure 23
pressures used effect of opening chest on 15
limitation by blow-off valve 15
Inflation rhythmic of the lungs—*continued*
importance of expiratory pause during 17
modern automatic devices for 86 (see also Respiration controlled automatic apparatus for)
resuscitation by 29 38
bellows etc for (see Resuscitation apparatus for)
condemned by Leroy 35
dangers of 36
Depaul advocates 41
Fell s apparatus 44
Vesalius use of 28
Injector Brat and Schmieden s use of 59
use in Aga Stille closed circuit apparatus 90–93
use in E & J Resuscitator 82
use in Pulmotor 81
Insufflation endotracheal for anaesthesia 13 67–77
apnoea during 68
apparatus for
Barthelemy and Dufour s 69
Ehrenfried s 75
Elsberg s first 72
Elsberg s portable 73
Janeway s intermittent 74
Kelly s 76
Meltzer and Auer s 67–68
Robinson s 75
Shipway s 76
experiments with
Hook s 30 68
Kuhn s 77 12
Nagel s 69
Robinson s 70
Sollman s 70
Volhard s 64 70
interruption of gas flow
Elsberg on 73
Janeway on 74
Meltzer on 68
intubation for difficulties Robinson on 70
Meltzer Robinson priority dispute 71
nitrous oxide anaesthesia by 79
uses in Britain 76 77
Insufflation rectal with tobacco smoke for resuscitation 107
Intubation (see also Tubes endobronchial and endotracheal)
beginnings of 39
blind tactile method Kuhn on 118
MacEwen on 111
Pugh on 103
Chaussier s cannula for 41
Crafoord s indirect introducer for 48 134
Depaul s cannula for 41
difficulties of Crafoord on 48
Curry on in the drowned 11
Meyer on 48
Robinson on 71
in croup Bouchut s attempt 43 108
O Dwyer s instruments for 42–43 111 158
in oedema of glottis Desault 43
MacEwen 111
in respiratory obstruction Monro 158
laryngoscopy for Elsberg 73 (see also Laryngoscope and Endoscope)
Leroy s tube introducer 36 134
Snow s use of 45 108

Intubation—*continued*
tracheal and bronchial development of 103
with cyclopropane and surface anaesthesia 148
Itard coins term pneumothorax 1

Jackson C advises Flagg on tube sizes 126
biography 155
bronchoscope tubes developed from 116 129
laryngoscope for intubation 123
used by Elsberg 73
laryngoscopy for anaesthetists 122
Peroral endoscopy and Laryngeal surgery 155
The Life of Chevalier Jackson 155
Jackson D E carbon dioxide absorption anaesthetic apparatus 145
improved clinical model 146
to and fro model for animals 147
Waters canister developed from 147
James N R apparatus for controlled respiration 94
Janeway H H assisted respiration apparatus 80
biography 155
cuffed tube for nitrous oxide anaesthesia 73
detachable cuff for endotracheal tube 123
intermittent insufflation apparatus 74
laryngoscope with curved blade 123
on controlled respiration 60 78 79 143
rhythmic inflation apparatus 78–79
rubber covered spiral wire tubes 79 80

Kausch W on vomiting in intestinal obstruction 117
stomach tube with cuff and pilot balloon 116
Kavannah G H Itard on pneumothorax 1
Keith A biography of Hawes 184
quotes Monro on intubation 128
reviews methods of artificial respiration 38
Kelly H and Burrage W L *Dictionary of American Medical Biography* 154 155 156 158
Kelly R L popularizes insufflation method 76
Keys T E *The History of Surgical Anesthesia* 29
Killian G biography 156
bronchoscopes 116
first removes foreign body from bronchus 116
laryngoscope used by Elsberg 73
the father of bronchoscopy 115
Kirchhof A C use of Burns Pressure Balance Resuscitator in anaesthesia 100
Kirstein A Autoscope 114
biography 156
develops laryngoscopy 115
on dangers of tracheoscopy 115
Kite C *An Essay on the Recovery of the Apparently Dead* 104
biography 156
Essays and Observations Physiological and Medical on the Submersion of animals etc 156
intubation tube 104
resuscitation pump 33
Kuhn F biography 156
Die perorale intubation 156
flexible metal endotracheal tube 118
blind insertion of 118
on insufflation method 77
positive pressure apparatus 56
revised model 57
circle carbon dioxide absorption model 58
uses endotracheal tube with 56
N

Kuhn F—*continued*
Reichert's principle use in laryngoscopy 136
suggests removal of secretions by suction 122
uses Trendelenburg chloroform cone 118

Labour criticism of anaesthesia for stopped by Snow 160
Larousse P *Grand Dictionnaire Universel de XIXe Siecle* 162
Laryngoscope Chevalier Jackson's for intubation 123
Elsberg on use of 73
Flagg's 128
Hill's the first slotted 119
Kirstein's Autoscope 114–115
Magill's original pattern 125
with curved blade Casteel's 123
Janeway's 123
Macintosh's 136
Miller's 123
use of Reichert's principle with 136
(see also Endoscope)
Laryngoscopy
for anaesthetists Jackson demonstrates 122
indirect use with Crafoord's endotracheal tube introducer 134
Larynx stenosis of Schrotter bougies for 109
Trendelenburg's tube with cuff for operations on 109
Leroy d'Etoilles J J biography 156
condemns inflation method 35
instructions for resuscitation 151
intubation instruments 36 134–135
safety bellows 36
Lewins iron lung pattern respirator 51
Lief P A on the cumulative effect of thiopentone 149
Lobectomy (see also Blocker bronchial)
bronchus blocker for 130
Loewy A and Schrotter H endobronchial catheter with cuff 117
London Coffee House formation of Humane Society at 31
Lotsch F positive pressure apparatus 6
Lucas G H W and Henderson V E, on cyclopropane anaesthesia 147
Lundy's pulmonary ventilator 83
Lung artificial 149
collapse of effect of surface tension on 4
forces causing 4
essential in positive pressure anaesthesia 11
deflation of controlled by water valve 46
elasticity of 4 5

Maatschappij Tot Redding Van Drenkelingen 30
Macintosh R R laryngoscope with curved blade 136
oesophageal tube with cuff 117
technique of laryngoscopy 135
use of Reichert's principle 136
Macintosh R R and Mushin W W Elihu's mouth to mouth method of artificial respiration 28
Magendie confirms Leroy's experiments 36
uses bellows for animal experiments 44

Gray T C on nitrous oxide thiopentone anaesthesia 149
Gray T C and Edwards F R on dangers of lung cysts 20
Green N W endotracheal tube with cuff and pilot balloon 119
  rhythmic inflation anaesthesia for experimental surgery, 78
Green N W and Janeway H H rhythmic inflation apparatus 60 78
  on value of controlled respiration 79
Griffiths H suggests bronchus blocker to Archibald 131
Griffiths H R and Johnson G F introduce curare into anaesthesia 148
Guedel A E and Treweek N controlled respiration in abdominal surgery 14
Guedel A E and Waters R M a new intratracheal catheter 1*6
  removable cuff for 127
Gurd F B et al spinal anaesthesia for thoracic surgery 14
  poor results of 15
Guthrie D *A History of Medicine* 159
Gwathmey J T insufflation anaesthesia with nitrous oxide 79

Hacker von sword swallowing method of oesophagoscopy 115
Haemorrhage effect of positive pressure anaesthesia on 12
Halton J bronchial occluder 137
Handgrip method Mullers 1
Harcourt Vernon chloroform apparatus 69
Hawes W biography 154
  formation of Humane Society 31
Head H endobronchial cannula with cuff 112
Heart artificial 149
Heidbrinck apparatus Mautz automatic device for 93
Henle Professor 60
Hess R endobronchial catheter 140
Hill W slotted laryngoscope 119
  slotted oesophagoscope 120
Hirsch A *Biographisches Lexikon* 153
Hirsch A and Hubotter F *Biographisches Lexikon* 162
Hook Robert animal experiments with inflation of lungs 29
  biography 154
  use of insufflation method 68
Humane Society Royal formation of 31 154
  resuscitation instruments 32 107
  endotracheal tube 32 107
Hunter John experiments on resuscitation with bellows 31
  member of Humane Society 154
Hyperventilation inhibition of respiratory centre by [illegible]

Infection spread of and the Coryllos McKesson tube 129
Inflation rhythmic of the lungs 14
  advantages of 21
  dangers with cyst of lung 20
  during pleural closure 23
  pressures used effect of opening chest on 15
    limitation by blow-off valve 15
Inflation rhythmic of the lungs—*continued*
  importance of expiratory pause during 17
  modern automatic devices for 86 (see also Respiration controlled automatic apparatus for)
  resuscitation by 29 38
    bellows etc for (see Resuscitation apparatus for)
    condemned by Leroy 35
    dangers of 36
    Depaul advocates 41
    Fell s apparatus 44
    Vesalius use of 28
Injector Brat and Schmieden s use of 59
  use in Aga Stille closed circuit apparatus 90–93
  use in E & J Resuscitator 82
  use in Pulmotor 81
Insufflation endotracheal for anaesthesia 13 67–77
  apnoea during [illegible]
  apparatus for
    Barthelemy and Dufour s 69
    Ehrenfried s 75
    Elsberg s first 72
    Elsberg s portable 73
    Janeway s intermittent 74
    Kelly s 76
    Meltzer and Auer s 67–68
    Robinson s 75
    Shipway s 76
  experiments with
    Hook s 30 68
    Kuhn s 77 122
    Nagel s 69
    Robinson s 70
    Sollman s 70
    Volhard s 64 70
  interruption of gas flow
    Elsberg on 73
    Janeway on 74
    Meltzer on 68
  intubation for difficulties Robinson on 70
  Meltzer Robinson priority dispute 71
  nitrous oxide anaesthesia by 79
  uses in Britain 76 77
Insufflation rectal with tobacco smoke for resuscitation 107
Intubation (see also Tubes endobronchial and endotracheal)
  beginnings of 39
  blind tactile method Kuhn on 118
    MacEwen on 111
    Pugh on 103
  Chaussier s cannula for 41
  Crafoord s indirect introducer for 48 134
  Depaul s cannula for 41
  difficulties of Crafoord on 48
    Curry on in the drowned [illegible]
    Meyer on 48
    Robinson on 71
  in croup Bouchut s attempt 43 108
    O Dwyer s instruments for 42–43 111 158
  in oedema of glottis Desault 43
    MacEwen 111
  in respiratory obstruction Monro 158
  laryngoscopy for Elsberg 73 (see also Laryngoscope and Endoscope)
  Leroy s tube introducer 36 134
  Snow s use of 45 108

Intubation—*continued*
tracheal and bronchial development of 103
with cyclopropane and surface anaesthesia 148
Itard coins term pneumothorax 1

Jackson C advises Flagg on tube sizes 126
biography 155
bronchoscope tubes developed from 126 129
laryngoscope for intubation 123
used by Elsberg 73
laryngoscopy for anaesthetists 122
Peroral endoscopy and Laryngeal surgery 155
The Life of Chevalier Jackson 155
Jackson D F carbon dioxide absorption anaesthetic apparatus 145
improved clinical model 146
to and fro model for animals 147
Waters canister developed from 147
Jame N R apparatus for controlled respiration 94
Janeway H H assisted respiration apparatus 80
biography 155
cuffed tube for nitrous oxide anaesthesia 79
detachable cuff for endotracheal tube 123
intermittent insufflation apparatus 74
laryngoscope with curved blade 123
on controlled respiration 60 78–79 143
rhythmic inflation apparatus 78 79
rubber covered spiral wire tubes 79 80

Kausch W on vomiting in intestinal obstruction 117
stomach tube with cuff and pilot balloon 116
Kavannah G D Itard on pneumothorax 1
Keith A biography of Hawes 184
quotes Monro on intubation 158
reviews methods of artificial respiration 38
Kelly H and Burrage W L *Dictionary of American Medical Biography* 154 155 156 158
Kelly R E popularizes insufflation method 76
Keys T E *The History of Surgical Anesthesia* 9
Killian G biography 156
bronchoscopes 116
first removes foreign body from bronchus 116
laryngoscope used by Elsberg 73
the father of bronchoscopy 115
Kirchhof A C use of Burns Pressure Balance Resuscitator in anaesthesia 100
Kirstein A Autoscope 114
biography 156
develops laryngoscopy 115
on dangers of tracheoscopy 115
Kite C *An Essay on the Recovery of the Apparently Dead* 104
biography 156
Essays and Observations Physiological and Medical on the Submersion of animals etc 156
intubation tube 104
resuscitation pump 33
Kuhn F biography 156
Die perorale intubation 156
flexible metal endotracheal tube 118
blind insertion of 118
on insufflation method 77
positive pressure apparatus 56
revised model 57
circle carbon dioxide absorption model 58
uses endotracheal tube with 56

Kuhn F—*continued*
Reichert s principle use in laryngoscopy 136
suggests removal of secretions by suction 122
uses Trendelenburg chloroform cone 118

Labour criticism of anaesthesia for stopped by Snow 160
Larousse P *Grand Dictionnaire Universal de XIVe Siecle* 162
Laryngoscope Chevalier Jackson s for intubation 123
Elsberg on use of 73
Flagg s 128
Hill s the first slotted 119
Kirstein s Autoscope 114–115
Magill s original pattern 125
with curved blade Cassel s 123
Janeway s 123
Macintosh s 136
Miller s 123
use of Reichert s principle with 136
(see also Endoscope)
Laryngoscopy
for anaesthetists Jackson demonstrates 122
indirect use with Crafoord s endotracheal tube introducer 134
Larynx stenosis of Schrotter bougies for 109
Trendelenburg s tube with cuff for operations on 109
Leroy d Etoilles J J biography 156
condemns inflation method 35
instructions for resuscitation 151
intubation instruments 36 134–135
safety bellows 36
Lewins iron lung pattern respirator 51
Lief P A on the cumulative effect of thiopentone 149
Lobectomy (see also Blocker bronchial)
bronchus blocker for 130
Loewy A and Schrotter H endobronchial catheter with cuff 117
London Coffee House formation of Humane Society at 31
Lotsch F positive pressure apparatus 62
Lucas G H W and Henderson V L on cyclopropane anaesthesia 147
Lundy s pulmonary ventilator 83
Lung artificial 149
collapse of effect of surface tension on 4
forces causing 4
essential in positive pressure anaesthesia 11
deflation of controlled by water valve 46
elasticity of 4 5

Maatschappij Tot Redding Van Drenkelingen 30
Macintosh R R laryngoscope with curved blade 136
oesophageal tube with cuff 117
technique of laryngoscopy 135
use of Reichert s principle 136
Macintosh R R and Mushin W W Elisha s mouth to mouth method of artificial respiration 28
Magendie confirms Leroy s experiments 36
uses bellows for animal experiments 44

Magill I W anaesthesia for maxillo-facial surgery 124
  bronchus blocker and tracheoscope 133
    modified pattern 133
    1949 pattern 139
  describes blind intubation 125
  develops endobronchial technique 131
  develops thoracic anaesthesia 131
  double insufflation catheter 125
    Flagg on 126
  laryngoscope original pattern 125
  on removal of secretions by suction 131
  rubber endobronchial tube 132
  spiral wire endobronchial tube and bronchoscope 132
  T connection for suction 131
Maloney J V et al assisted respiration apparatus 80
Marshall Hall method of resuscitation 44
Matas R biography 157
  modifies Fell O Dwyer apparatus 45
    Dorrance on use of 121
  on Fell O Dwyer apparatus for chest surgery 44
  on O Dwyer tube 43
  on pleural adhesions 44
  on resuscitation pumps 31
  in rhythmic inflation for chest surgery 44
  on spinal anaesthesia 157
  on treatment of shock 157
Mautz F R automatic respiration apparatus 93
  use with Heidbrinck machine 93
Maxillo-facial surgery anaesthesia for Magill and Rowbotham 124
Maydl, O Dwyer type tube and introducer 113
Mediastinum flap of 7
  flexibility of effects on paradoxical respiration 5
  shift of minimized by positive pressure 128
Meltzer S J biography 157
  dispute with Robinson on origin of insufflation method 71
  on interruption of gas flow in insufflation 68
Meltzer S J and Auer J insufflation apparatus and method 67–68
  effect of work on intubation and laryngoscopy 119
Meyer W biography 157
  carbon dioxide accumulation in positive pressure anaesthesia 64
    prevention by allowing collapse of lungs 11 64–65
  on difficulties of intubation 48
  positive negative pressure apparatus 54
  use of adrenalin-saline drip 65
Mickulicz von and Elsberg 54
Mickulicz von and Sauerbruch 48 160
Miller Abbott tubing 138
Miller R A laryngoscope with curved blade 123
Monro A biography 158
  intubation for respiratory obstruction 158
  on bellows for live anatomy demonstration 31
Moody J [illegible] et al clawed bronchus blocker 138
Moore I on Kirstein s Autoscope 115
Mørch E T *Anaesthest* 91
  Blease Pulmoflator 97
  Respirator 94
    disadvantages of 95 96
      McKesson apparatus and 94
  Respirator 1952 pattern 100
  Spiropulsator mechanism 91
Motley [illegible] H et al Bennett resuscitator 101
  on expiratory pause during rhythmic inflation 17
Mouth to mouth artificial respiration 151
Moyer C H and Beecher H K on carbon dioxide accumulation in positive pressure anaesthesia 11
Muller s Hand Grip method 1
Mully K upper lobe bronchus blocker 140
Murphy F T positive pressure apparatus 53
Murray John resuscitation apparatus 31
Musgrove A H on Blease Pulmoflator 97
Mushin W W on Elisha s method of artificial respiration 28
  self inflating cuff 137
Mushin W W and Rendell Baker L on nitrous oxide pethidine anaesthesia, 19 97 149
MacEwen W endotracheal tube for oral operations and respiratory obstruction 111
McKesson anaesthetic apparatus use with Mørch s respirator 94
  Coryllos endotracheal tube 129

Nagel experiments with insufflation 69
Negative pressure anaesthesia 12 49
  compared with positive pressure method 52
  Meyer s apparatus 54
  Sauerbruch s operation chamber 49
Neff W B et al pethidine nitrous oxide anaesthesia 140
  valve for Oxford Vaporizer 46
Neu M nitrous oxide apparatus with Rotameters 144
Nitrous oxide anaesthesia
  apparatus for
    Bunnell s valve for positive pressure 62
    Crafoord s modified Spiropulsator 90
    Frenckner s Spiropulsator 86
    Jackson s carbon dioxide absorption 145 146
    Janeway s assisted respiration 80
    Janeway s tube with cuff for 79
    Neu s with Rotameters 144
  controlled respiration with 143
  injector operated by on Stille apparatus 90 91 97
  pethidine technique 19 97 149
  thiopentone and cumulative effect of 149
  replaces cyclopropane 149
  use with diathermy 149
  use of carbon dioxide absorber with 149
Nooth s pump for resuscitation 33
Northrup W P on Fell O Dwyer apparatus 44
  on O Dwyer 158
Nosworthy M D reviews technique for chest surgery 135

Obstruction intestinal vomiting prevented by Kausch tube 117
  prevented by Macintosh tube 117
Obstruction respiratory Kites tubes for 104
  Monro on intubation for 158
O Dwyer J biography 158
  endotracheal tube for Fell apparatus 44 111
  tube and instruments for use in croup 42 111
  Matas opinion of 43
Oesophageal tube Coleman s 106
  James Curry s 33
Oesophagoscope Hill s slotted 120
Oesophagoscopy sword swallowing method Von Hacker 115

Operative stimuli effects of 11
O Shaughnessy L 62 (see Sauerbruch F and)
Overholt R H control of secretions by posture 136
Overholt R H and Langer L *The technique of Pulmonary Resection* 136
Oxford Vaporizer controlled respiration with 137
Mushin s self inflating cuff for 137
Neff valve for 46

Pagel J *Biographisches Lexikon* 152 156
Paracelsus (von Hohenheim) biography 159
on resuscitation by inflation of lungs 29
Paradoxical respiration (see Respiration paradoxical)
Pendelluft of Brauer 6
Pendulum air 11
Pethidine nitrous oxide anaesthesia 19 97 149
Pettigrew T J *Medical Portrait Gallery* 161
Pia and Garcy laryngeal catheters for resuscitation 31
Pigeon Nagel s insufflation experiments with 69
Pinson K B and Bryce A G apparatus for controlled respiration and constant suction 93
Pleural closure catheter and water seal 24
inflation of lung during 23
suction during 23
Pleural space negative pressure of 4
Pneumothorax coined by Itard 1
residual after thoracotomy 3
Pneumothorax syndrome (see also Respiration paradoxical)
and one lung anaesthesia Gale and Waters 128
modern solutions of 149
Sauerbruch s work on 48
theory of causation 47
Position on table effect on paradoxical respiration 7
Positive pressure anaesthesia 10 48
acute dilation of stomach following 18
apparatus for Brat and Schmieden s 59
Brauer s first 51
Brauer s second 52 comments on 53
Bunnell s loaded valve for 62
Drager 65
Kuhn s 56
Kuhn s revised 57
Kuhn s carbon dioxide absorption pattern 58
Lotsch s 62
Meyer s 54
Morriston Davies 63
Murphy s 53
Robinson s 55
Tiegel s first 60
Tiegel s second 60
Tiegel Henle 61
carbon dioxide accumulation during 11 64
cardiac output and 12
chloroform and 47 51 52 56–61 63 143
compared with negative pressure method 52
dead space and 11
deaths following 64
disadvantages of 12
ether and 53 60–62 65
Frenckner s experiments 86
Giertz experiments on 86
paradoxical respiration and 10
Quenu and Longuet s method 47
replaced by rhythmic inflation 94 148

Positive pressure anaesthesia—*continued*
rhythmic pressure variations necessity of 11 64
Sauerbruch F and O Shaughnessy L on 12
venous pressure and 12
Wilms self inflating cuff for 137
with one lung anaesthesia Gale and Waters 128
Posture control of secretions by Beecher 135
Overholt 136
Priestly experiments on respiration 39
Pugh Benjamin Air Pipe 103
A Treatise of Midwifery 103
biography 159
Pulmoflator Blease 1946 pattern 97
1950 pattern 98
mode of action 98–99
Pulmonary infection spread of by paradoxical respiration 7
Pulmotor Drager for resuscitation 81

Quenu and Longuet on pleural adhesions 47
on positive pressure anaesthesia 47

Radiography use for insertion of Archibald s blocker 131
Mully s blocker 140
Zavod s bronchospirometric catheter 130
Rahn H effect of positive pressure on the dead space 11
Reichert s principle use in laryngoscopy 136
Relaxants (see also Curare Gallamine)
dangers with cysts of lung 20
Respiration artificial (see also Resuscitation and Rhythmic inflation)
French instructions for 151
mouth to-mouth Elisha 28
mouth to mouth French on 151
without movement of lungs Hook 29
Respiration assisted 18
Janeway s apparatus for 80
Maloney s apparatus for 80
Respiration controlled
abolition of paradoxical respiration by 15
advantages of 17
and one lung anaesthesia Rovenstine 132
apparatus (non automatic) for
Brat and Schmieden s 59
Green on 78
Neff valve 46
laboratory use of 48
Tuffier and Hallion s 46
automatic apparatus for
advantages of 20
criteria for 91
disadvantages 20
early automatic devices 78
pressure controlled apparatus
Bennett Resuscitator 100
Blease Pulmoflator (1950) 98
Burns Pressure Balance Resuscitator 99
Janeway s 81
Mautz 93
Morch s Respirator (1952) 100
Spiropulsator Frenckner s 87 91
Crafoord s modification 89
1940 pattern 90
1950 pattern 92
Williams 101

Re piration controlled
automatic apparatus for—*continued*
pump type apparatus
disadvantages of 95–96
Blease Pulmoflator (1946) 97
James 94
Janeway s 74
Janeway and Green s 78
Mørch s Respirator 94
Pinson s 95
danger of acapnia 18
dangerous with cyst of lung 20
depth of anaesthesia during 18 21 6
difficulties in early application 143
dilation of stomach during 18
disadvantages of 17
displaces positive pressure anaesthesia 94
effect on cardiac output 17
Guedel uses in abdominal surgery 14
Mushin s self inflating cuff for 137
pressure in lungs during 16
with ether 143
Respiration paradoxical 5
abolition by controlled respiration 15
effect on cardiac output 7
effect of coughing on 7 8
effect of posture on 7
effect of respiratory obstruction on 7
effect of size of thoracotomy opening on 6
effect on spread of infection 7
harmful effects 5
reduced by chloroform 143
shock following 7
Respiratory centre reflex inhibition of 18
Respiratory movements function of 68
Respiratory obstruction caused by secretions 8
effect on paradoxical respiration 7
Resuscitation by inflation of the lungs 28
apparatus for 31–42 44–45
Cap s tube and pump 31
Courtois Hans pump 31
Curry s tube and instruments 33 104–106
Desgranges pump 31
Erichsen s pump 37
Fell s 44
Fell-O Dwyer 44
Fine s leather tube 31
Goodwyn on 33
Hook on 29
Hunter s bellows 31 36
Kite s pump and tube 33 104
Lewin s iron lung 30
Lundy's Pulmonary Ventilator 83
Monro s bellows 31
Murray s 31
Nooth s pump 33
Paracelsus on 29
Pia and Garcy s laryngeal catheters 31
routine instruction for use of 151
Royal Humane Society s 32
Vesalius on 28–29
Woillez Spirophore 50
in the newly born,
Chaussier s cannula bag and mask 39 41
Chaussier on household bellows for 39
Depaul s cannula 41
Pugh s Air Pipe 103
Ribemont s tube 42 110
Resuscitation—*continued*
bellows use for 29–32 35–37 39 44–45
condemned by Leroy 35
Elisha s mouth to mouth method 28
Oxygen use for 38
Sylvester and Marshall Hall methods 44
Tossach uses mouth to mouth method 28
Resuscitator Bennett s 100
Burns Pressure Balance 99
E & J 82
Rhythmic inflation (see Respiration controlled)
Ribemont A A A biography 159
tube for resuscitation of the new born 42 108 110
Richardson B W *The Life of John Snow* 160
Roberts F W on positive pressure anaesthesia and secretions 12
Robinson H W biography of Hook 154
Robinson S disputes originality of Meltzer and Auer insufflation method 71
insufflation apparatus 73
insufflation experiments 70–71
on Brauer s apparatus 53
on difficulty of intubation 71
positive pressure apparatus 55
Rotameter Neu s nitrous oxide/oxygen apparatus with 144
Roth Drager apparatus 51 52 (see also Drager)
Rovenstine E A endobronchial tube 133
one lung anaesthesia and controlled respiration 132
Rowbotham S insufflation anaesthesia for maxillo facial surgery 124
and Hill s laryngoscope 124
two catheter method 124
uses double insufflation catheter 125
Royal Humane Society 31
apparatus for resuscitation 32 107
Royal Society Hook demonstrates artificial respiration at 26
Rusby L N and Thompson V C Thompson s blocker 138
Ruth H S et al endobronchial tube 139

Sauerbruch F biography 160
effect of work on differential pressure 52
investigates pneumothorax syndrome 48
negative pressure operating chamber 49
on effect of opening chest on circulation 48
uses Tiegel Henle apparatus 61
Sauerbruch F and O Shaughnessy L *Thoracic Surgery* 1 [illegible] 14
Muller s Handgrip 1
on value of aspiration of secretions 14
positive pressure anaesthesia 12
Schrotter bougies for laryngeal stenosis 109
Eisenmenger s tube based on 113
Schwann carbon dioxide absorption mine rescue apparatus 146
Secretions bronchial
Archibald on control by bronchus blocker 130
control by
bronchial tampon Crafoord 135
endobronchial intubation 128
posture Beecher 135
posture Overholt 136
effect on pneumothorax [illegible]
effect of positive pressure anaesthesia on 12

Secretions bronchial—*continued*
removal by coughing 14
spinal anaesthesia and 14
removal by suction 14
Coryllos McKesson tube for 129
first suggested by Kuhn 122
Pinson s apparatus for 95
Sauerbruch on 14
Shields S spinal anaesthesia for thoracic surgery 14
Shipway F E insufflation apparatus 76
Shock caused by paradoxical respiration 7
cyclopropane shock 148
Snow J anaesthesia for experimental chest surgery 45
biography 160
intubation in animals 45 108
Mode of Communication of Cholera 160
on carbon dioxide absorption 147
On chloroform and other anaesthetics 45
Queen Victoria given chloroform by 160
The Inhalation of Ether 160
Sollman insufflation experiments 70 71
Soper R L on Burns Pressure Balance Resuscitator in anaesthesia 100
Spencer N R *History of British Midwifery* 159
Spinal anaesthesia for thoracic surgery
removal of secretions by coughing 14
poor results of 15
Gale and Waters on 14
Gurd et al on 14
Shields on 14
Matas pioneer of 157
Tuffier pioneer of 161
Spiral wire use for connecting tubes
Coleman 106
Kite 104
Trendelenburg 109
use for endotracheal or endobronchial tubes
Coryllos McKesson 129
Flagg 126
Janeway 79
Magill 132
Pugh 103
Ruth et al 139
Spiropulsator ahead of current practice 94
Crafoord s first modification 89
Crafoord on disadvantages of 90
cyclopropane with 90
diagram of circuit and mode of operation 88
diagram of valve mechanism 91
explosion with 92
first commercial model 90
Frenckner s 86–90
method of carbon dioxide absorption 90
use of Waters canister with 92 93
use of vacuum cleaner with 92
use in Scandinavia 93
with Aga Stille apparatus (1950) 92
Stephen E D S upper lobe bronchus blocker 141
Stille closed circuit absorption apparatus 90–92
Stockum W J van endotracheal tube with cuff 116
Stomach dilation of with controlled respiration 18
with positive pressure 18
Suction during closure of pleura 23
removal of secretions by 14
first suggested by Kuhn 122
Pinson s apparatus 95
Sauerbruch opinion of 14
Surface tension of pleural surfaces effect on collapse of lung 4
Sylvester method of artificial respiration 44
Tarnier abortion catheter adapted by Wolffberg 110
Thiopentone danger of cumulative effect 149
nitrous oxide anaesthesia 149
Thompson V C bronchus blocker 138
Thoracoplasty Brauer on 152
Coryllos McKesson tube for 129
limitation of spread of infection by 129
Thoracotomy influence of size of 1 4
opening plugged by fingers 1
Tiegel M dilation of stomach following positive pressure anaesthesia 18
first positive pressure apparatus 60
second positive pressure apparatus 60
use of water valve by Tuffier 47
vomit catcher 60
Tiegel Henle positive pressure apparatus Sauerbruch s uses 61
To and fro absorption (see Carbon dioxide absorption)
Tobacco smoke rectal insufflation of 107
Tossach W on mouth to-mouth resuscitation 28
Tracheoscope Magill s for inserting bronchus blockers 133
Voltolini s 110
Tracheotomy advocated by Trousseau 43
Vesalius uses 29
Trendelenburg F biography 160
chloroform cone 109
used by Doyen 114
used by Kuhn 118
tracheotomy tube with cuff 109
Trousseau advocates tracheotomy 43
condemns Bouchut s tube for use in croup 43
Tube endobronchial
Bjork and Carlens 140–141
Frenckner s bronchoscope for insertion of 131
Gale and Waters 128
Head s 112
Hess 140
Loewy and Schrotter s 117
Magill s spiral wire 132
Rovenstine s 133
Ruth et al s spiral wire 139
Wengo s 112
Wolffberg s 110
Zavod s 130
endotracheal
Annandale s 11
Coryllos McKesson 129
Crafoord s indirect vision introducer for 134
Dorrance s with cuff 79 121
Doyen s 114
Eisenmenger s with cuff and pilot balloon 113
Flagg s 126
Frenckner s with cuff 129
Green s with cuff and pilot balloon 119
Guedel and Waters with cuff 126
Janeway s with detachable cuff 78 80 123
Kuhn s flexible metal 56 118
Lotsch s,
MacEwen s 111
Maydl s 113
Morriston Davies with cuff 63 122

Tube endotracheal—*continued*
Mushin s self inflating cuff for 137
Spiral wire (see Spiral wire)
Tuffier s with cuff 114
Van Stockum s with cuff 116
Wilm s self inflating cuff for 137
endotracheal for resuscitation,
Cap s 31
Curry's 33–35 105
Curry s modified 106
Fine s 31
Kite s for resuscitation 104
Leroy's 36 134
Leroy's introducer for 36 134
O Dwyer s 44 111
Pia and Garcy s 31
Royal Humane Society s 3 107
endotracheal for resuscitation of the newly born
Chaussier s 41 106
Depaul s 41 107–108
Pugh s 103
Ribemont s 42 110
endotracheal for use in croup
Bouchut s 43
O Dwyer s 42 111
Tube nostril Chaussier s 40
Curry's 34–35 105 106
Tube stomach Kausch s with cuff and pilot balloon 117
Macintosh s with cuff 117
Tube tracheotomy Trendelenburg s with cuff 109
Tuffier T biography 161
O Dwyer pattern tube with cuff 114
rhythmic inflation method 46
Tuffier and Hallion rhythmic inflation anaesthesia 45

Velden von den biography of Brauer 152
Venous pressure effect of positive pressure on 12
Ventilator Lundy s Pulmonary 83
Ventilatory capacity decreased effect on anaesthesia 8
Verworn, experiments with carbon dioxide 64
Vesalius A. biography 161
De Corporis Humanis Fabrica 9
inflation of lungs in live anatomy demonstrations 28
Victoria Queen Snow gives chloroform to 160
Vital capacity importance of in open chest 8
Volhard F biography 161
experiments with insufflation 64 70
rhythmic inflation apparatus 70
Voltolini Tracheoscope 110
Vomit catcher Tiegel s 60
Vomiting during anaesthesia, 12 61
in intestinal obstruction
prevented by Kausch tube 117
prevented by Macintosh tube 117

Waters R M and cyclopropane anaesthesia 147
canister for carbon dioxide absorption 147
and artificial respiration 148
used with Aga Stille absorption apparatus 91–93
on Schwann s carbon dioxide absorption apparatus 146
removal of secretions by suction 15
(see also Guedel and Waters 126 and Gale and Waters 128)
Waters R. M and Gale J W spinal anaesthesia for thoracic surgery 14
endobronchial tube 128
Water seal drainage following thoracotomy 24
signs of atelectasis shown by 25
Water valves Brauer on disadvantages of 54
on Kuhn s apparatus 56
on Tiegel s first apparatus 60
on Tiegel s second apparatus 60
on Tiegel Henle apparatus 61
use for limiting inflation pressure 15
use in positive pressure 11
use to control deflation of lungs 46
Watrous W G et al 22
Wengo B endobronchial catheter 112
Wiggin S C laryngoscope with curved blade 123
Williams T M automatic breathing attachment for Boyle s apparatus 101
Wilms M biography 162
self inflating cuff for positive pressure anaesthesia 137
Woillez E J biography 162
spirophore for resuscitation 50
Wolffberg S endobronchial catheter 110

Zavod W A. bronchospirometric catheter 130